Hipotenusa: Journal of Mathematical Society
Volume 7 Issue 1 Year 2025
ISSN: 2716-3156
Website: https://ejournal.uinsalatiga.ac.id/index.php/hipotenusa/index

Integrating Augmented Reality in RME-Based Digital Learning: Impact on Students' Problem-Solving Ability

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DOI: 10.18326/hipotenusa.v7i1.3768

Article submitted: March 10, 2025
Article reviewed: April 11, 2025
Article published: May 07, 2025

Abstract

This research investigates the efficacy of combining Augmented Reality (AR) technology with the Realistic Mathematics Education (RME) methodology in developing students' mathematical problem-solving capabilities. The investigation examines how the AR-RME integration functions as a potential educational innovation for boosting learner involvement and conceptual comprehension. This research employs a combined design incorporating numerical and descriptive-analytical frameworks. A cohort of 17 secondary school adolescents engaged in AR-RME-facilitated learning across five instructional sessions. Evaluation of participants' problem-solving proficiency was conducted through comparative pre-intervention and post-intervention assessments based on Polya's four-stage methodology: issue identification, procedural planning, implementation of strategies, and outcomes evaluation. Systematic observations were conducted to evaluate student engagement levels. The results of the observations showed the enthusiasm and active participation of the students during the learning. Statistical analysis using paired t-tests revealed a significant improvement in problem-solving skills ($t = 8.742$, $p < 0.05$), with the average score increasing to 74.81%. These findings show that AR-RME effectively improves spatial reasoning and understanding of three-dimensional geometry concepts, especially on cubes and blocks. This study confirms that AR-RME is an innovative approach that enhances problem-solving skills and becomes a more interactive and effective learning alternative to conventional methods.

Keywords: Augmented Reality, geometry learning, mathematical problem-solving, Polya method, Realistic Mathematics Education.

INTRODUCTION

Developments in the digital era have transformed mathematics education through technology-based platforms that enhance interactive and dynamic learning via visualization, simulations, and hands-on experiences (Bulut & Ferri, 2023; Lai & Cheong, 2022). Digital learning tools improve engagement and allow students to adapt to their needs (Zulfiqar et al., 2023). Among these innovations, Augmented Reality (AR) is particularly effective in mathematics by bridging abstract concepts with tangible visualizations (Tarng et al., 2024). Unlike physics and engineering, where AR aids in simulations and design (Cai et al., 2023), mathematics benefits significantly due to its reliance on spatial reasoning and symbol manipulation (Kounlaxay et al., 2021). AR enables students to interactively explore geometric shapes and algebraic functions interactively, enhancing conceptual understanding, spatial skills, and problem-solving abilities.

Learning technology such as AR has become increasingly significant as various challenges arise in mathematics learning, particularly in developing students' problem-solving abilities. Mastery of solving mathematical problems is essential for equipping students to deal with the complexities of today's world (Liljedahl & Cai, 2021). Nevertheless, conventional mathematics instruction often emphasizes rote memorization and procedural routines rather than fostering a deep conceptual understanding, which hinders students' ability to internalize and apply abstract mathematical concepts in unfamiliar contexts (Arifin et al., 2020). Studies reveal that learners often encounter difficulties with spatial visualization, symbolic reasoning, and translating mathematical ideas into real-life situations, which are key components for effective problem-solving (Arifin et al., 2021). These limitations highlight the need for innovative and contextual learning strategies, such as Realistic Mathematics Education (RME), which emphasizes meaningful problem-solving through real-world contexts, fostering deeper mathematical understanding and engagement (Tumangger et al., 2024).

Innovations in mathematics learning continue evolving to create more meaningful student experiences. Realistic Mathematics Education (RME) has effectively narrowed the divide between abstract mathematical ideas and practical, real-world applications by utilizing contextual learning grounded in authentic, real-life scenarios (Rezat et al., 2021). This approach helps students connect mathematical concepts with daily experiences, enhancing their understanding (Hidayat et al., 2022). However, conventional RME often struggles to present real-world contexts dynamically and interactively, particularly when dealing with abstract or complex mathematical phenomena, such as visualizing three-dimensional geometric transformations (Cevikbas et al., 2024). AR has the potential to enrich RME by offering immersive and interactive visual representations, which allow students to engage with mathematical concepts in a more intuitive and stimulating manner (Verbruggen et al., 2021). Integrating AR within the RME framework can improve the approach's effectiveness by making mathematics instruction more dynamic, context-rich, and personally meaningful (Weigand et al., 2024).

The development of AR technology opens up new opportunities in increasing the effectiveness of RME-based mathematics learning. AR enables interactive visualization that overcomes the limitations of conventional methods in bridging abstract concepts with real applications (Wang & Li, 2024). Research findings show that incorporating Augmented Reality in mathematics instruction significantly improves students' conceptual grasp, boosts their learning motivation, and develops their problem-solving abilities (Jdaitawi et al., 2023). Furthermore, AR contributes to nurturing essential 21st-century competencies, including critical thinking, creativity, and digital literacy, by delivering engaging, hands-on learning environments that promote collaboration and the application of problem-solving strategies (Alkhabra et al., 2023). As such, embedding AR within RME holds promise as a forward-thinking educational strategy, transforming mathematics into a more engaging, contextually grounded, and relevant subject for students (Tarng et al., 2024).

A review of studies involving the integration of AR and RME in mathematics education highlights several research gaps that warrant further exploration. AR effectively increases engagement and visualizes abstract concepts, but it is less optimal in developing problem-solving skills because students focus more on the visual aspect (Bulut & Ferri, 2023). Meanwhile, RME can connect mathematical concepts with the real world but faces challenges in representing dynamic situations without technological support (Tumangger et al., 2024). Several studies have shown that integrating AR into RME can overcome the limitations of each approach and create a more interactive and immersive learning experience (Altmeyer et al., 2020). Therefore, further studies are needed to explore the technical integration of AR and RME and assess their effectiveness in improving students' mathematical problem-solving skills. This research is expected to provide empirical insights that support the development of technology-based mathematics learning theories and practices.

In response to the identified research gaps, an in-depth investigation is necessary to construct a learning design that combines AR technology with the RME framework. Earlier studies have shown that using AR in education can positively influence students' comprehension and motivation (Altmeyer et al., 2020; Putrie & Syah, 2023) At the same time, RME has been acknowledged for its success in enhancing learners' problem-solving abilities through contextually grounded instruction (Fitriawan et al., 2023). However, studies combining these two approaches remain scarce, highlighting the need for further exploration (Muhaimin et al., 2024). This study primarily aims to design and assess the effectiveness of AR-enhanced instructional models grounded in the RME philosophy. Considering the crucial role of interactive and stimulating learning settings, the specific aims of this research are: (1) to develop a mathematics learning framework that merges AR and RME principles and (2) to investigate how such a model influences students' problem-solving competency (Kumalasari et al., 2022). Ultimately, the outcomes of this research are projected to offer meaningful contributions to advancing innovative, contextually relevant mathematics instruction and expand the academic discourse surrounding the integration of AR in RME-based educational practices.

Based on theoretical and empirical studies, this study proposes a working hypothesis regarding the effectiveness of integrating AR technology in RME-based mathematics learning. Specifically, it posits that integrating AR in RME-based learning will significantly improve students' ability to solve mathematical problems compared to the traditional application of RME. Prior evidence has indicated that AR contributes to conceptual comprehension through its capacity to deliver dynamic and interactive visual aids (Putrie & Syah, 2023; Tarng et al., 2024). At the same time, RME focuses on connecting mathematical ideas to authentic, real-life situations (Fitriawan et al., 2023). Both strategies reflect constructivist learning principles, which maintain that learners construct knowledge most effectively through engaging and meaningful experiences (Hajirasouli & Banihashemi, 2022). Evaluating this proposed hypothesis will yield valuable insights into how AR integration can further optimize mathematics instruction grounded in RME principles.

To develop innovative and effective mathematics learning, this research has made several important contributions to the development of mathematics education. First, it develops a new pedagogical model integrating AR and RME, enriching the literature on mathematics learning innovations (Nurmasari et al., 2024; Putrie & Syah, 2023; Wang & Li, 2024). Secondly, the study offers substantiated evidence concerning how AR technology can be effectively incorporated into RME-based instruction, especially in addressing the persistent issue of improving students' problem-solving abilities (Cevikbas et al., 2024; Kumalasari et al., 2022). Thirdly, the outcomes of this research deliver actionable insights in the form of pedagogical modules and strategic guidelines to support educators in integrating AR into mathematics teaching. These outputs help elevate students' learning experiences through applicable classroom solutions (Weigand et al., 2024). Thus, this study enriches the theoretical foundation of mathematics learning and offers applicable solutions that can be directly implemented in classroom teaching.

The development of digital technology has changed the educational paradigm, including in Indonesia, which actively encourages technological integration through the Independent Curriculum and School Digitalization Program (Kurniawan et al., 2024; Syarifuddin et al., 2024). This policy aligns with the global shift towards Education 4.0, which highlights the importance of utilizing technology in project-based learning while also fostering the development of critical thinking and problem-solving skills (González-pérez & Ramírez-montoya, 2022; Timotheou et al., 2023). This research aims to deliver concrete recommendations to enhance the implementation of AR in the RME framework, thereby promoting more interactive, contextual, and aligned mathematics learning with national educational priorities.

METHODS

This research adopts an explanatory sequential mixed-method approach structured into two principal phases. In the initial phase, a quantitative method was employed to evaluate enhancing students' problem-solving abilities before and after implementing an Augmented Reality-based instructional model grounded in the Realistic Mathematics Education (AR-RME) framework. After obtaining the quantitative findings, the second phase applied a qualitative approach involving classroom observations, student questionnaires, and analysis of students' responses to gain richer insights into their reasoning patterns in solving mathematical tasks. Combining statistical data with contextual interpretations enables a more comprehensive evaluation of the effectiveness of AR-RME-based learning (Stern et al., 2020).

This study engaged 17 eighth-grade students (aged between 14 and 15 years) from a junior high school in Palembang. Participants were chosen through purposive sampling, targeting individuals who met the specific requirements of the study. The sample included nine female and eight male students, offering a balanced gender representation. Using purposive sampling ensured that the selected students possessed characteristics aligned with the research aims (Stern et al., 2020). The selection criteria are based on two main aspects: first, experience in using digital learning tools, which is assessed through an initial questionnaire, and second, the level of mathematical proficiency, which is classified based on the scores of the last formative test with the categories of low (<70), medium (70–85), and high (>85). This classification refers to the school's evaluation standards and the results of discussions with the classroom mathematics teacher. This was achieved by relating findings to prior studies and recognizing patterns that might be applicable in similar educational settings. Previous research has indicated that even with small sample sizes, significant insights can be gained in educational intervention contexts (Corujo-Vélez et al., 2020).

The quantitative method utilized in this research adopts a single-group pretest-posttest model (O_1 X O_2). In this framework, O_1 represents the initial assessment of students' problem-solving abilities conducted before the intervention, X refers to the implementation of an instructional treatment through AR-RME-based learning, and O_2 indicates the final evaluation administered after the intervention (Corujo-Vélez et al., 2020; Timotheou et al., 2023). Although this design does not include control groups, bias mitigation measures are carried out with various strategies. First, controlling learning variables is done by equalizing all participants' learning materials, durations, and procedures. Second, documentation of implementation conditions is implemented to ensure uniformity of interventions. Third, an analysis of individual student development was carried out to see the impact of the intervention in more depth, not just based on the average group comparison. Fourth, a combination of quantitative and qualitative analysis is used to strengthen the validity of the results, considering both numerical trends and contextual factors that affect students' problem-solving skills.

The research instrument utilized in this study for assessing problem-solving capabilities was constructed by adopting Polya's conceptual framework consisting of four principal phases: a comprehensive understanding of the issue, formulation of resolution strategies, application of solution steps, and examination of outcomes. Three specialists in mathematics education pedagogy conducted a thorough review of the instrument to establish content validity, after which refinements were implemented based on their professional recommendations. The instrument's reliability assessment was conducted by calculating Cronbach's alpha coefficient, yielding a value of 0.85, demonstrating satisfactory internal consistency in measuring problem-solving proficiency within educational settings (Adom et al., 2020).

The qualitative approach in this study involves classroom observation, questionnaires based on the Likert scale, and analysis of student answers. Classroom observations were conducted over five learning sessions to observe student engagement, the effectiveness of the use of AR, and the application of RME principles in learning. Cohen's kappa analysis ($\kappa = 0.82$) was used to improve the reliability of observations, which showed a high level of agreement between observers (Cole, 2023; Díaz et al., 2023). In addition, a Likert scale-based questionnaire was used to evaluate students' perceptions of AR-RME-based learning, including aspects of student engagement, ease of understanding mathematical concepts, and the effectiveness of technology in supporting learning (Tanujaya et al., 2021). To gain a deeper understanding of students' thinking strategies, student answer analysis was carried out based on the Polya model, which aims to identify patterns of problem-solving strategies and challenges faced by students at each stage of solving mathematical problems (Szabo et al., 2020).

To enhance research validity and trustworthiness, methodological triangulation was employed by comparing data gathered via classroom observations, learner surveys, and examination of participants' responses. This methodological approach safeguards against single-source bias by verifying findings through multiple data-gathering techniques (Stern et al., 2020). Consequently, this investigation offers a multifaceted understanding of how AR-RME-oriented instruction influences learners' mathematical problem-solving abilities, encompassing their engagement in educational activities and cognitive approaches applied when addressing mathematical challenges.

RESULTS AND DISCUSSION

Learning Implementation

The implementation of mathematics learning that integrates the RME and AR approaches is structured into a series of progressive learning activities. At the initial stage, students engage with contextual problems related to three-dimensional geometric structures, specifically focusing on prisms and cuboids, as presented in the RME e-module. Subsequently, students explore geometric properties, including volume, nets, and surface area, through an AR application that allows them to manipulate virtual models in a three-dimensional space. This interactive visualization aids in bridging students' informal and formal mathematical understanding.

During the learning process, students initially work individually to analyze problems and attempt solutions using AR technology. They then engage in small group discussions to compare problem-solving strategies and develop a shared understanding. Finally, teachers facilitate class discussions, guiding students to synthesize their findings into formal mathematical concepts. The integration of AR not only enhances students' visualization skills but also addresses common misconceptions in spatial reasoning by providing interactive, real-time manipulation of geometric structures (Nadzri et al., 2023).

The following subsections present specific indicators of student engagement and conceptual development at each stage of the learning process:

Use of Context

Figure 1. Traditional Palembang carved cabinet

Aligned with the principles of RME, learning activities begin with real-life contexts digitized into an interactive e-module. Students are introduced to authentic geometric cases, such as the structure of traditional Palembang carved cabinets (Figure 1), where they identify prism components in the lower compartments and cuboid elements in the main storage sections. Success in this stage is indicated by students' ability to correctly recognize and describe geometric features within the real-world object. This contextualization strengthens connections between mathematical concepts and their practical applications while fostering student engagement (Fitriawan et al., 2023).

Model Usage

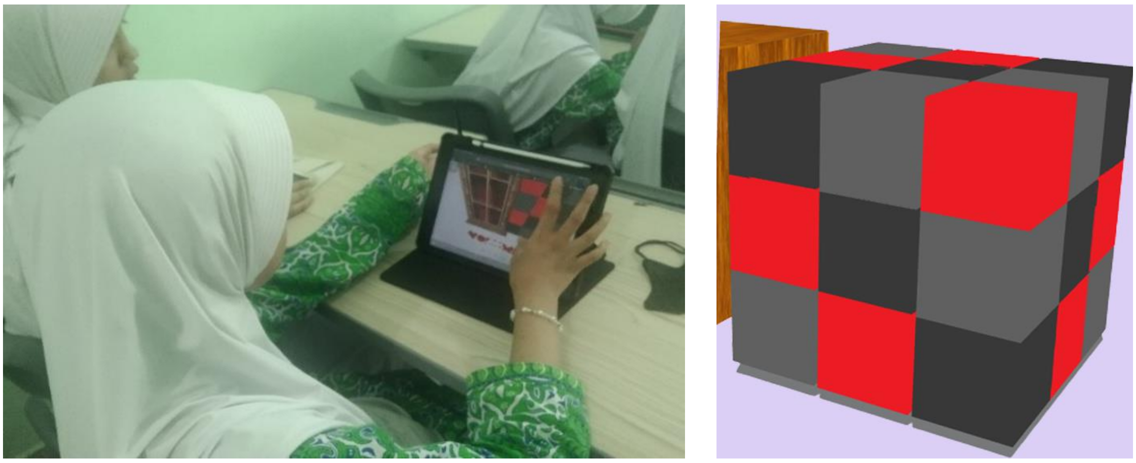

Figure 2. Students use AR in learning

Mathematical modeling is facilitated through AR simulations, where students manipulate virtual nets and calculate surface area and volume of three-dimensional objects (Figure 2). These models provide a bridge between informal reasoning and formal geometric concepts. An indicator of success in this phase is students' ability to construct and compare different nets for a given solid and accurately compute surface area and volume. Research by Putrie & Syah (2023) highlights the role of AR in improving spatial visualization, which is crucial for understanding these geometric properties.

Knowledge Construction

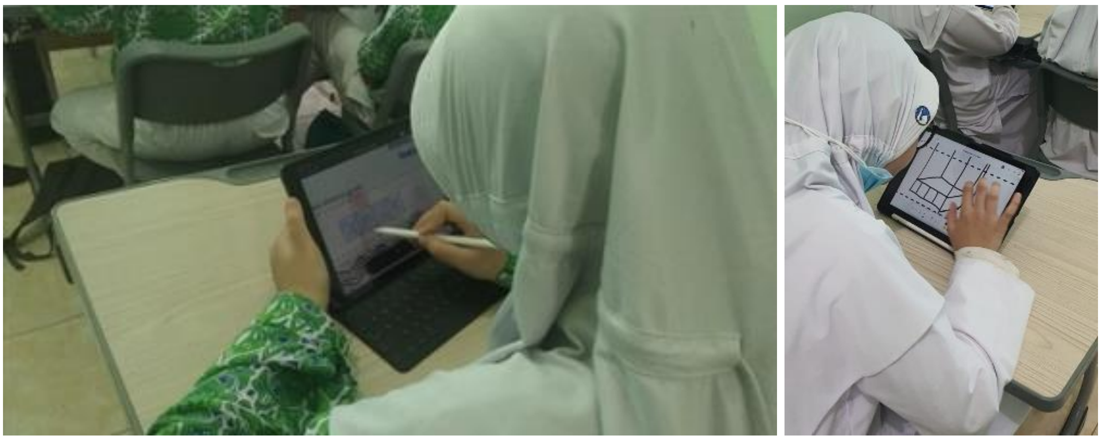

Figure 3. Students construct their knowledge

Students construct knowledge through a structured learning sequence: working individually to explore problems, engaging in peer discussions to refine their understanding, and synthesizing their findings into formal conclusions (Figure 3). Success is demonstrated by students articulating their reasoning, justifying their solutions, and correcting misconceptions collaboratively. The scaffolded approach aligns with prior findings that collaborative AR-enhanced learning improves conceptual understanding (Guntur & Setyaningrum, 2021).

Interactivity and Linkage

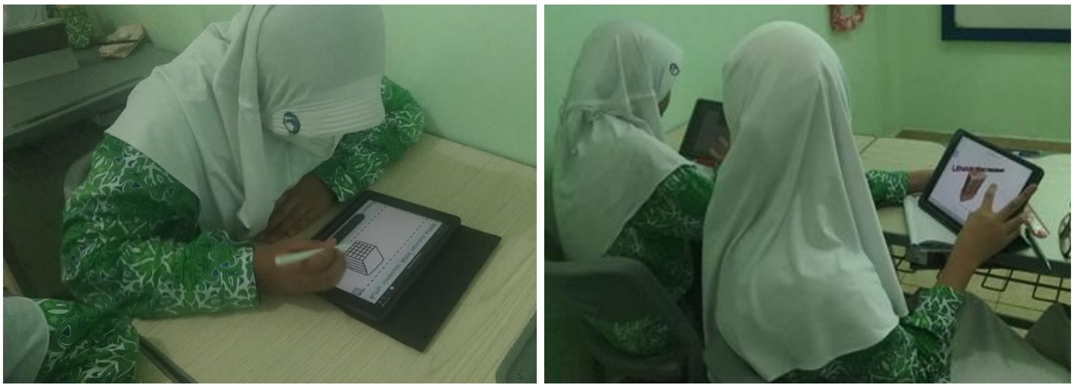

Figure 4. Students relate concepts that have already been learned

AR integration promotes interactivity by allowing students to dynamically manipulate geometric models and discuss their observations with peers and instructors (Figure 4). The relationship between different mathematical properties, such as the relationship between the net, surface area, and volume is an important concern. Observable success indicators include students who demonstrate an increased ability to conceptually relate these traits and apply them in new problem-solving scenarios. Research by Tarng et al. (2024) supports the claim that AR improves geometric understanding through interactive learning experiences.

The integration of Augmented Reality (AR) in Realistic Mathematics Education (RME)-based learning plays an important role in overcoming students' difficulties in spatial reasoning. AR provides real-time feedback and hands-on exploration, allowing students to visualize abstract geometric concepts more effectively. This ability reduces cognitive load and improves conceptual understanding (Altmeyer et al., 2020). In addition, as an approach that aligns with RME principles, AR encourages student involvement in mathematical problem-solving. Studies show that AR can create an interactive learning environment that stimulates critical thinking and creativity, especially in geometry learning, where students can manipulate 3D objects and explore concepts such as volume and surface area (Al-Ansi et al., 2023; Putrie & Syah, 2023).

Beyond visualization, AR supports students in the problem identification stage, helping them understand concepts before solving problems independently or collaboratively. By facilitating a structured learning process, which starts from individual exploration to class synthesis, AR plays a role in improving students' ability to build mathematical knowledge. Research by Arifin et al. (2021) highlights that scaffolding in problem solving fosters creativity through systematic mathematics and structured reasoning, where AR can play a role as scaffolding in problem solving. These findings are in line with previous research that confirmed the effectiveness of the RME approach in improving students' mathematical problem-solving skills (Melaibari & Ismail, 2023). In addition, the integration of AR in mathematics learning has a meaningful educational impact, especially in increasing student active participation (Volioti et al., 2023). Thus, the synergy between AR and RME not only strengthens mathematical visualization but also enhances conceptual understanding and overall student engagement.

Observation Results

The observation results were obtained from the implementation of learning carried out by students using AR-assisted RME teaching materials in each activity by adjusting the principles of RME and assessing the results of student work in each activity by looking at problem-solving indicators. The recapitulation of the observation results is presented in the following figure 5.

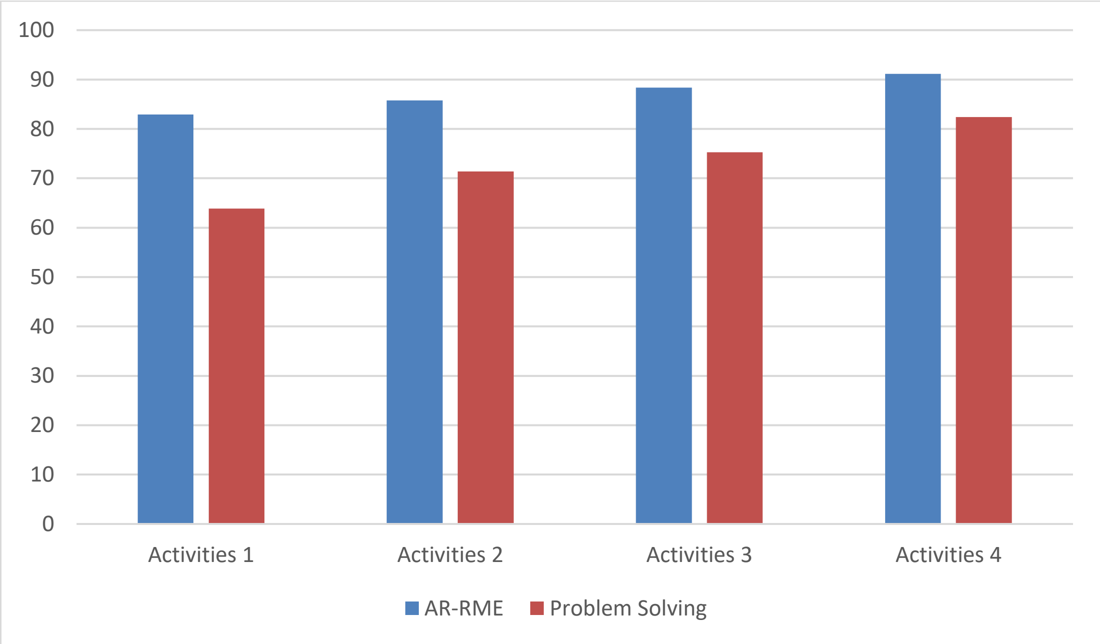

Figure 5. Learning Activity Data

Based on the data from the observation of student activities and the work on learning activities, there are positive developments in both RME activities and the problem-solving process. PMRI activity showed a consistent increase from Activity 1 to Activity 4, where the lowest score was recorded in Activity 1 at 82.94%. It reached the highest value in Activity 4 at 91.18%, with an overall average of 87.06%. The significant increase was especially seen in the move from Activity 3 to Activity 4, which increased by 2.82%.

In line with this, students' problem-solving skills also show an improvement trend. Starting with a score of 63.89% in Activity 1, problem-solving skills continued to increase until they reached 82.39% in Activity 4, with an overall average of 73.24%. The most significant increase occurred in the move from Activity 3 to Activity 4, which experienced an increase of 7.13%.

The data indicates a positive correlation between PMRI activities and students' problem-solving skills. Along with the increasing application of PMRI in learning, students' problem-solving skills consistently improve. This is evident in Activity 4, where both aspects reach their highest scores, showing that the PMRI approach effectively improves students' skills in solving mathematical problems. This increase in ability consistently shows the effectiveness of the RME approach integrated with AR, which is in line with the findings of Richardo et al. (2023) about the role of AR in improving creative thinking skills in geometry learning.

Furthermore, the researcher also analyzed student responses related to mathematics learning using the AR-assisted RME approach. Student responses were obtained by giving a questionnaire containing four indicators at the end of the activity. There are 24 positive and negative questions with two answer choices. Then, the questionnaire results were analyzed, and a recapitulation was obtained, as shown in Table 1.

Table 1. Recapitulation of Student Responses

Indicator	No	Yes
Students' interest and enthusiasm	94.12	5.88
Learning strategies and styles	94.96	5,04
AR-integrated RME learning experience	93.14	6,86
Comfort and ease of learning	94.12	5,88
Average	94.09	5.92

Based on the data of the recapitulation of student responses to learning that integrates RME and AR, it can be described that overall, students give very positive responses, with an average percentage of "Yes" responses reaching 94.09% and "No" responses only 5.92%. The highest percentage is shown in the strategy and learning style indicators, which reached 94.96%, indicating that the integration of RME and AR is very suitable for how students learn. Meanwhile, the indicators of student interest and enthusiasm, as well as the aspects of comfort and ease of learning, showed the same percentage of 94.12%, indicating that this learning succeeded in arousing students' interest and creating psychological conditions that are supportive of learning. In the AR-integrated RME learning experience indicator, the percentage reached 93.14%, which, although slightly lower than other indicators, still showed a very positive response.

The high percentage of positive responses on all indicators (above 93%) proves that students receive the integration of RME and AR in mathematics learning. This indicates that a learning approach that combines RME and AR has succeeded in creating an engaging learning experience, supporting effective learning strategies, and creating a pleasant learning atmosphere for students. This high enthusiasm is in line with the research of Poçan et al. (2023), which confirmed that mobile technology in mathematics learning has a positive effect on student motivation and learning performance

Problem-Solving Ability Test

To analyze the effectiveness of mathematics learning using AR-integrated RME teaching materials on problem-solving skills, a quantitative descriptive analysis was carried out on the results of the initial and final test of students. The analysis was carried out by examining the results of the student's work that were adjusted to Polya's problem-solving steps, both in terms of suitability and accuracy of the aspects written. The measurement of learning effectiveness adopts the N-Gain method to identify changes in students' capabilities before and after the learning intervention. The results of the calculation of the N-Gain test are presented in the following table 2.

Table 2. N-Gain Test Results of Pretest-Posttest Data

	N	Minimum	Maximum	Mean	Std. Deviation
Pretest	17	8.00	63.00	32.82	16.024
Postest	17	62.00	95.00	83.00	11.096
N_Gain_Skor	17	.46	.93	.7481	.1481
N_Gain_Persen	17	45.95	92.54	74.81	14.81
Valid N (listwise)	17				

The analytical findings yielded N-Gain measurements demonstrating progression between the initial assessment and final evaluation. Examination of N-Gain coefficients revealed a minimum value of 0.46 and maximum value of 0.93, with a calculated mean of 0.7481 and statistical dispersion of 0.1431. When expressed as percentages, the minimum improvement registered at 45.95%, while the maximum improvement reached 92.54%, yielding an aggregate enhancement of 74.81% with a computed standard deviation measuring 14.82%. Referencing the derived mean N-Gain coefficient of 0.7481 (equivalent to 74.81%), this improvement falls within the "High" classification parameters as the coefficient exceeds the 0.7 threshold. Such quantification suggests that the instructional intervention substantially enhanced participants' mathematical problem-solving skills.

To corroborate findings from the descriptive assessment, inferential statistical procedures were implemented to examine the proposed research hypotheses. Before conducting the main analysis, preliminary assumption verification was performed, encompassing examinations of data distribution normality and variance homogeneity. The outcomes from these foundational statistical assessments are documented in subsequent Tables 3 and 4.

Table 3. Normality Test Results

	Shapiro-Wilk		
	Statistic	df	Sig.
pretest	.936	17	.270
posttest	.895	17	.056

The normality test results were performed using Shapiro-Wilk, which is more appropriate for small samples (n = 17). The analysis results showed that the pretest data had a significance value of 0,270 (> 0,05) and posttest 0,056 (> 0,05), which means that the data was normally distributed.

Table 4. Homogeneity Test Results

	Levene Statistic	df1	df2	Sig.
Based on Mean	.447	1	32	.509

The homogeneity test using Levene's test showed a significance value based on a mean of 0,509 (> 0,05), which means that the variance of the data is homogeneous or has the same distribution. This indicates that the homogeneity assumption has been met so that parametric statistical analysis can continue. These results also show that the groups of data compared have equivalent characteristics in terms of variability.

Based on the fulfillment of these two assumptions, namely normality, and homogeneity, the analysis can be continued using parametric statistics with paired t-tests presented in the following Table 5.

Table 5. Paired t-Test Results

Paired Differences					t	df	Sig.
			95% Confidence Interval of the Difference				
Mean	Std. Deviation	Std. Error Mean	Lower	Upper			(2-tailed)
-5.01765	14.0545	3.4087	-57.4026	-42.9503	-14.720	16	.000

The analytical examination of paired sample t-test calculations produced a t-statistic of -14.720 with degrees of freedom totaling 16 and a two-tailed probability value (p-value) of 0.000, which falls below the predetermined alpha threshold of 0.05. The calculated difference between means was -50.1765, accompanied by a standard deviation measurement of 14.0545 and a standard error mean of 3.4087, while the 95% confidence boundaries extended from -57.4026 to -42.9503. Given that the probability value is less than the 0.05 criterion, the null hypothesis is unsupported, confirming a statistically meaningful variation between assessment scores before and after intervention. The observed mean differential provides evidence that participants' performance metrics improved following the implementation of the intervention, reinforcing the educational effectiveness of the RME methodology integrated with AR technology in strengthening mathematical problem-solving skills. This substantial performance supports the assertion that this pedagogical innovation significantly enhances learners' mathematical comprehension and problem-solving skills. However, subsequent research employing larger participant pools would be beneficial to substantiate these conclusions further.

This favorable outcome corresponds with research by Melaibari & Ismail (2023), who established that the RME pedagogical framework substantially strengthens learners' capabilities for mathematical problem resolution by utilizing mathematical representational forms as connecting elements between mathematical conceptual understandings and solution-finding processes. Yuhasriati et al. (2022) further corroborates the assertion that RME methodologies contribute advantageously to students' mathematical proficiency and intellectual development. Regarding practical applications, incorporating AR technological elements within RME instructional contexts delivers robust visual reinforcement, particularly for comprehending geometric principles. This observation receives validation from Guntur & Setyaningrum (2021), whose investigations revealed that AR implementation enhances learners' three-dimensional cognitive abilities and mathematical problem-solving competencies in geometric contexts. Additionally, Nadzri et al. (2023), documented consistent results, identifying beneficial educational outcomes from AR component integration within geometry curricula.

Examining student work products yielded several noteworthy observations regarding their cognitive processing approaches when addressing assessment questions. The initial challenge required participants to compute the surface area of a cubic structure using specified dimensional parameters. Figure 6 below illustrates a representative example of solution methodology employed by students.

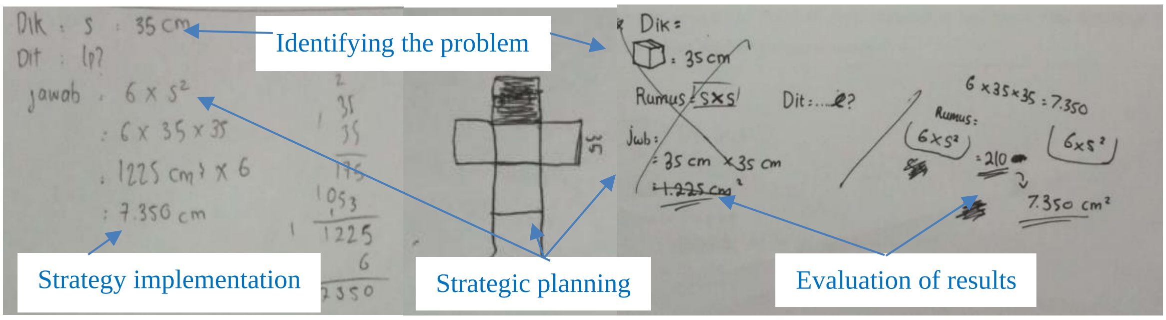

Figure 6. Student Response to Question 1: Calculating the Surface Area of a Cube

The analysis of student responses reveals their systematic approach to solving the problem of calculating the surface area of a cube. At the problem-understanding stage, all 17 students (100%) correctly identified the cube's edge length as 35 cm. Additionally, 13 out of 17 students (76%) sketched the cube's nets to visualize the problem, reinforcing Seah & Horne's (2020) findings that visual representation aids the transition from concrete to abstract thinking in geometry. In the calculation stage, 15 out of 17 students (88%) initially wrote "35 × 35" before correcting it to "6 × 35 × 35", demonstrating an evaluation and refinement process. This aligns with Frey et al. (2022), who emphasized the role of experience in developing problem-solving strategies. Using cube nets and self-correction strategies highlight students' spatial reasoning and metacognitive awareness, essential for mastering geometric concepts.

In question number 2, students are faced with the calculation of the capacity of a large cube in accommodating smaller cubes. The completion done by the students can be seen in figure 7.

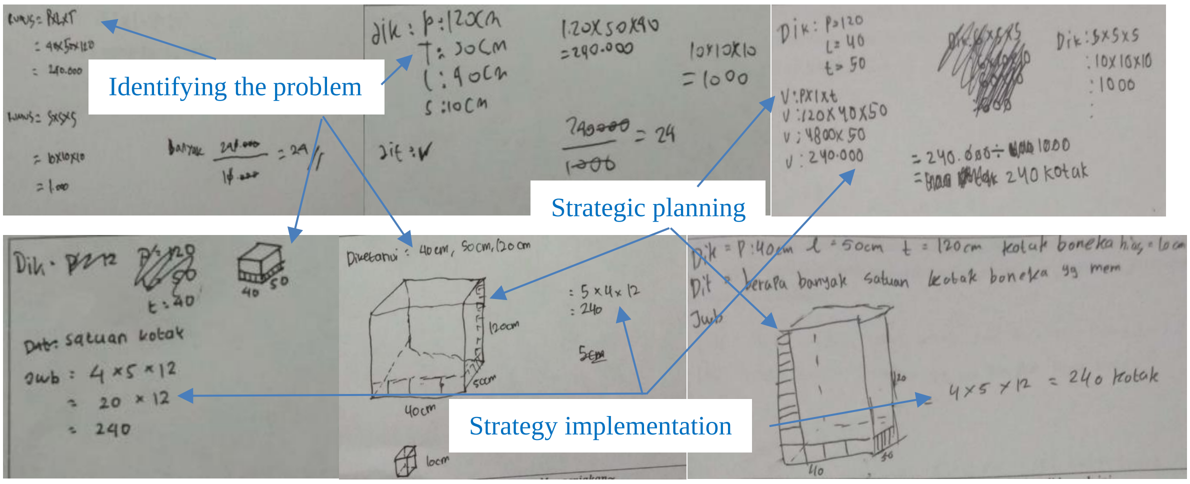

Figure 7. Student Response to Question 2: Problem-Solving in Cost Calculation

The analysis of student responses to question 2 highlights their ability to solve mathematical problems related to cost calculation. At the problem-understanding stage, all 17 students (100%) successfully identified key information, including the box dimensions (50 cm) and price per unit (120,000). Additionally, 14 out of 17 students (82%) included a 3D sketch to clarify the problem, supporting Verschaffel et al. (2020), who emphasized the role of visual representation in mathematical understanding. At the strategy planning stage, 12 out of 17 students (71%) systematically applied the multiplication formula ($4 \times 5 \times 12 = 240$) to determine the total number of items, demonstrating strong conceptual understanding. This aligns with findings by İlhan & Aslaner (2020), which suggest a positive relationship between spatial reasoning and geometric problem-solving ability. Furthermore, 9 out of 17 students (53%) made corrections or refinements in their worksheets, indicating metacognitive awareness, a key factor in successful problem-solving, as highlighted by Chytrỳ et al. (2020). Integrating visual representation, spatial reasoning, and systematic calculations suggests a comprehensive understanding among students in solving geometry-related cost problems.

In question number 3, students are asked to determine the surface area of the block. The results of the completion carried out by the students are presented in Figure 8.

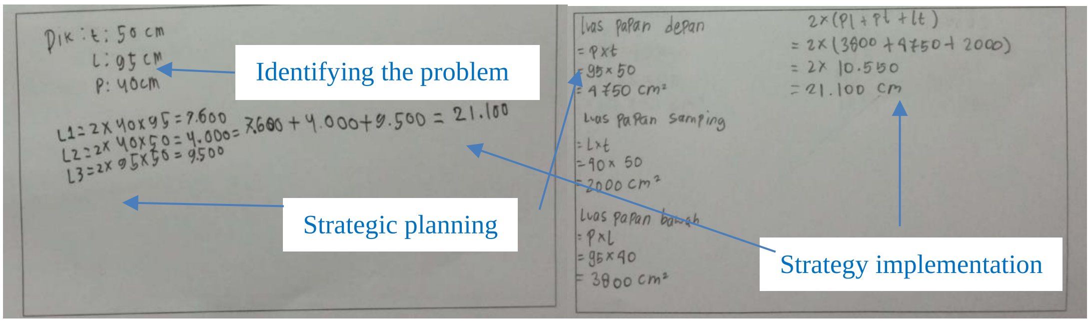

Figure 8. Student Response to Question 3: Calculating the Surface Area

The analysis of student responses to question 3 reveals their ability to apply problem-solving strategies in calculating the surface area of a rectangular prism. At the problem-understanding stage, all 17 students (100%) successfully identified the prism's dimensions, aligning with Hutajulu et al. (2022), who emphasized the importance of conceptual understanding in geometry. In the strategy planning stage, 15 out of 17 students (88%) correctly wrote the surface area formula $L = 2(pl + pt + lt)$, while 2 students (12%) initially attempted an alternative approach before making corrections. During strategy implementation, 14 out of 17 students (82%) substituted the values accurately and obtained the correct result of 21,100 cm². Additionally, 11 out of 17 students (65%) verified their answers by performing separate calculations for each surface area component, demonstrating a structured approach to problem-solving. This aligns with Riyadi et al. (2021), who highlighted the benefits of Polya's problem-solving steps in organizing mathematical thinking. Furthermore, the role of spatial reasoning in this process supports findings from Li et al. (2023), who emphasized the significance of visual-spatial ability in solving geometric problems.

In question number 4 it is almost similar to question number 2, only the application of question number 2 related to blocks and number questions related to cubes. The results of the students' answers to question number 4 are as shown in figure 9.

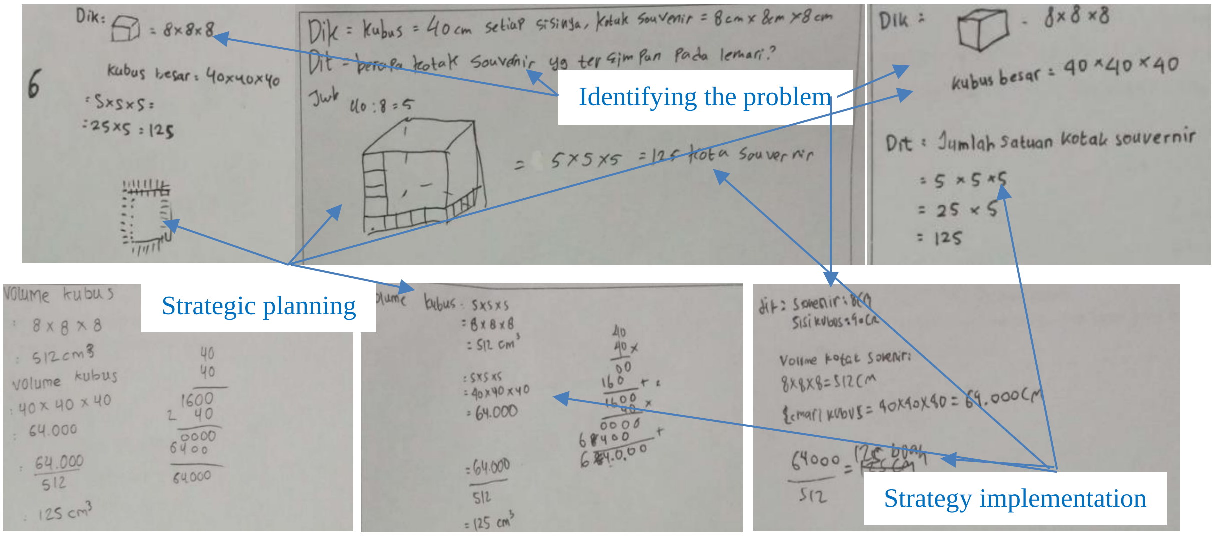

Figure 9. Student Response to Question 4: Calculating the Surface Area of a Cube

The analysis of student responses to question 4, which involves calculating the surface area of a cube, provides insights into their problem-solving strategies. At the problem-understanding stage, all 17 students (100%) successfully identified the cube's edge length as 40 cm. In the strategy planning stage, 14 out of 17 students (82%) drew a cube sketch before writing the surface area formula ($6 \times s^2$), while 3 students (18%) directly wrote the formula without a sketch. At the strategy implementation stage, all students correctly calculated $6 \times 40 \times 40$ and obtained 9,600 cm^2. Furthermore, 15 students (88%) verified their final answers by ensuring correct unit notation. These findings align with Mohaghegh & Furlan (2020), who found that students who systematically apply problem-solving steps tend to achieve more accurate results. Similarly, İbili et al. (2020) highlighted the importance of visual representation in enhancing students' comprehension and problem-solving skills in geometry.

In question number 5, students are asked to calculate the volume of a block-shaped space. The visualization of the completion done by the students can be observed in figure 10.

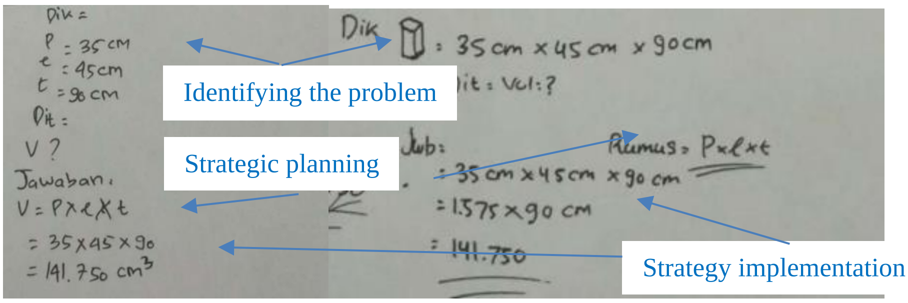

Figure 10. Student Response to Question 5: Calculating the Volume of a Block

Analyzing students' responses to question 5, which focuses on calculating the volume of a block, provides insights into their problem-solving strategies. At the problem-understanding stage, all 17 students successfully identified the block's dimensions: length = 35 cm, width = 25 cm, and height = 20 cm. At the strategy planning stage, 15 out of 17 students (88%) correctly wrote the volume formula ($V = p \times l \times t$), while 2 students (12%) initially attempted alternative approaches before revising their work. At the strategy implementation stage, all students calculated $35 \times 25 \times 20$ and obtained the correct result of 17,500 cm^3. Furthermore, the re-examination process was evident in 14 out of 17 students (82%), who ensured proper unit notation in their final answer. These findings align with Sorby et al. (2022), who demonstrated that students' ability to correctly organize information and apply formulas correlates with problem-solving success. Similarly, Zhang et al. (2022) emphasized that a strong conceptual understanding of three-dimensional space enhances students' accuracy in solving volume-related problems.

The results of the analysis showed that students had strong mathematical problem-solving skills, particularly in geometry and volume calculation. Their ability to systematically organize thoughts reflects the effectiveness of structured problem-solving approaches. Visual representations, such as three-dimensional sketches and cube nets, play an important role in improving spatial reasoning as well as conceptual understanding, in line with previous research that emphasized the importance of visualization in mathematics learning (Seah & Horne, 2020). As a visualization medium, augmented reality (AR) allows for the direct exploration of three-dimensional shapes, thereby improving students' understanding of the surface area and volume of the building. Research by Arifin et al. (2024) also shows that the development of AR-based E-Modules for cube surface area materials in the context of the Palembang Closet has been empirically validated and proven to be effective in increasing student engagement in learning.

In addition, students' metacognitive awareness is seen in their ability to evaluate and improve problem-solving strategies, as seen from the corrections they make during calculations (Frey et al., 2022). The problem-solving process follows a structured framework in which many students successfully apply and verify mathematical formulas correctly. This reinforces the importance of a systematic approach, such as the Polya method, in guiding students to face complex problem-solving tasks (Riyadi et al., 2021). These findings also indicate that spatial reasoning, conceptual understanding, and metacognitive awareness are key components in developing effective mathematical problem-solving skills (Chytrỳ et al., 2020; İlhan & Aslaner, 2020). The integration of visual representations with structured problem-solving strategies not only improves students' calculation accuracy but also strengthens their ability to analyze and refine problem-solving approaches.

CONCLUSION

This research explores a novel methodology combining Augmented Reality (AR) systems with Realistic Mathematics Education (RME) principles to enhance students' capacity to solve mathematical problems. The study results indicate that this integration improves academic performance and cultivates a more profound conceptual understanding and involvement in mathematical learning. Unlike previous studies that explored AR and RME separately, this investigation provides substantiated data demonstrating their joint efficacy, revealing considerable growth in students' capacity to connect abstract mathematical theories with practical, real-world implementations.

Analysis of the learning outcomes verified that participants using the AR-RME approach demonstrated measurably superior development in problem-solving capabilities. Furthermore, qualitative assessments identified heightened learner enthusiasm, greater classroom engagement, and a more dynamic educational setting than traditional teaching methods. These outcomes highlight the transformative capacity of AR technology to render complex mathematical abstractions more comprehensible and relevant.

Although this study's findings are promising, several limitations should be acknowledged. The research was conducted in a single classroom setting with only 17 participants, which may limit the generalizability of the results. Moreover, participants were selected based on accessibility rather than using a sampling method to represent a broader population. Consequently, future studies are encouraged to involve larger and more diverse samples across various educational environments to validate the effectiveness and scalability of the AR-RME approach.

In addition to methodological considerations, students' technological proficiency is also a critical factor. Educators and educational policymakers should explore how AR-based instructional strategies can be developed to enhance student motivation and learning outcomes. Furthermore, future research should examine the long-term impact and potential challenges of implementing AR in different educational settings to maximize its possible benefits in mathematics instruction and understanding.

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