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The effect of PMRI assisted by augmented reality on circle for students' problem-solving ability

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Abstract
Mathematical problem-solving ability among students remains low in conventional learning environments. The integration of Augmented Reality (AR) into the Indonesian Realistic Mathematics Education (PMRI) approach facilitates visualization of abstract concepts and promotes contextual learning. This study analyzes the effect of PMRI-based circle learning assisted by AR on students' problem-solving abilities. A quantitative approach was employed using a One Group Pretest pretest-posttest design with 35 eleventh-grade students from SMA Srijaya Negara Palembang. Data were collected through a mathematical problem-solving test based on Polya's four stages: understanding the problem, devising a plan, carrying out the plan, and looking back, administered before and after the intervention. The Shapiro–Wilk test indicated that the data were normally distributed (pretest = 0.084; posttest = 0.309, both > 0.05). Paired sample t-test analysis revealed a pretest mean score of 19.37 and a posttest mean score of 66.51, with a mean difference of 47.14. The t-test result (t = -23.053, Sig. (2-tailed) < 0.001) indicated a significant difference between pretest and posttest scores. These findings demonstrate that the PMRI-based learning design assisted by AR is effective in improving students' problem-solving abilities through contextual learning experiences and interactive visualization. The results suggest that integrating PMRI with Augmented Reality in circle learning represents an effective instructional innovation for enhancing students' problem-solving abilities.

Keywords: augmented reality; circle; PMRI; problem solving

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I. Introduction

Problem-solving ability constitutes a core competency in mathematics education, requiring critical, creative, communicative, and collaborative thinking skills aligned with 21st-century educational demands (González-pérez & Ramírez-montoya, 2022; Klang, Karlsson, Kilborn, Eriksson & Karlberg, 2021). This competency is essential not only for solving procedural tasks but also for addressing real-world problems that require in-depth analysis and data-driven decision-making (Cano & Lomibao, 2023; Nilimaa, 2023). Within mathematics education, problem solving is instrumental in enabling students to comprehend abstract concepts, apply them to everyday situations, and develop logical reasoning (Hartmann, Krawitz & Schukajlow, 2021; Wijayanti, Zulkardi, Susanti & Meryansumayeka, 2025).

Despite its importance, multiple studies indicate that Indonesian students' problem-solving abilities remain relatively low. Many students are unaccustomed to addressing non-routine problems, resulting in difficulties with understanding context, formulating strategies, and interpreting solution. (Sriwahyuni & Maryati, 2022; Yayuk, Purwanto, As'Ari & Subanji, 2020). These challenges are attributed to low student engagement and the continued prevalence of teacher-centered instructional approaches (Ghafar, 2023; Hokor & Sedofia, 2021; Tsegaw, Valcin & Lambert, 2021). Consequently, students often memorize formulas without understanding their conceptual and struggle to connect mathematics learning to real-life contexts (Ncube, Luneta, Africa & Ncube, 2025; Nilimaa, 2023).

An approach considered effective in addressing these challenges is Pendidikan Matematika Realistik Indonesia (PMRI), which is based on Hans Freudenthal's Realistic Mathematics Education (RME). PMRI posits that mathematics is a human activity constructed from students' everyday contexts (Zulkardi, Putri & Wijaya, 2020). In PMRI-based instruction, students are encouraged to explore contextual problems, construct mathematical models, and draw reflective conclusions (Firsta & Susanti, 2024; Komariyatiningsih et al., 2023). This methodology facilitates the connection between abstract concepts and concrete experiences, thereby enhancing the meaningfulness of learning and supporting the development of problem-solving abilities.

Advancements in educational technology have made the integration of digital media a significant innovation in mathematics instruction. Augmented Reality (AR) is a promising technology that interactively overlays three-dimensional virtual objects onto real environments (Aditya, Ilma, Susanti & Aisyah, 2022; Flavin, Chung & Wang, 2025). AR enables the transformation of abstract mathematical concepts into concrete visualizations that are accessible to students (Schutera et al., 2021; Velázquez & Méndez, 2021; Wu, Jiang, Long & Zhang, 2024). For instance, in geometry or functions, students can directly observe shapes and transformations, facilitating visual and contextual understanding of relationships among elements (Nindiasari et al., 2024). The integration of PMRI and AR can foster learning experiences that are more contextual, interactive, and meaningful (Aboud & Ali, 2025; Chonchaiya & Srithammee, 2025; Flavin et al., 2025). PMRI encourages students to approach problems grounded in real situations, while AR provides visual representations that support concrete exploration of mathematical concepts. This combination is expected to alleviate students' difficulties in understanding abstract concepts and increase their engagement. Furthermore, AR visualization helps students recognize the connections between context and mathematical concepts, enabling the development of more effective problem-solving strategies.

Previous studies have investigated PMRI and Augmented Reality independently; however, few have integrated both approaches specifically within the context of circle learning or assessed students' problem-solving abilities using Polya's stages. This gap underscores the need to comprehend how the integration of PMRI and AR can facilitate the problem-solving process in contexts that require concrete visualization. The present study addresses this gap by designing PMRI-based instruction aided by AR for circle concepts and quantitatively examining its effect on students' problem-solving abilities, representing a novel integration in the existing literature.

Given this context, the present study examines the impact of a PMRI-based learning design supplemented by Augmented Reality on the problem-solving abilities of eleventh-grade students at SMA Srijaya Negara Palembang. The study aims to both describe the effectiveness of PMRI and AR implementation and quantify their impact on students' mathematical problem-solving abilities through a quantitative approach. The findings are anticipated to contribute to the development of innovative instructional models that integrate contextual approaches with digital technology in mathematics education.

II. Research Method

This study employed a quantitative approach with a pre-experimental approach and a one-group pretest-posttest design. This design was used to determine the effect of treatment on learning outcomes by comparing pre- and post-treatment scores in the same group. Through this design, researchers were able to observe the extent to which learning based on Indonesian Realistic Mathematics Education (PMRI) with the assistance of Augmented Reality (AR) influenced students' mathematical problem-solving abilities.

The research design is described as follows:

Table 1. One-group pretest–posttest design

Pretest	Treatment (X)	Posttest
Y_1	PMRI based learning assisted by AR	Y_2

Notes

Y_1: Problem-solving ability score before the treatment

X: Implementation of PMRI-based learning assisted by AR

Y_2: problem-solving ability score after the treatment

Researh Subject

This research was conducted at Srijaya Negara Senior High School in Palembang during the even semester of the 2024/2025 academic year. The subjects were 35 eleventh grade students. The age range of participants was 16–17 years old, with approximately balanced gender representation (17 females and 18 males). The class was selected using a purposive sampling technique, considering that the class was studying material relevant to the implementation of PMRI learning. All students fully participated in the learning activities, pretest, and posttest.

Instruments

The instrument used in this study was a mathematical problem-solving ability test in the form of an open-ended essay. The test was developed based on Polya's four stages of problem-solving: (1) understanding the problem, (2) planning a solution strategy, (3) implementing the strategy, and (4) reviewing the results. The instrument consisted of five questions structured with reference to the basic competencies and learning context of PMRI. A Polya-based analytic rubric with a 0–4 scoring scale was used to assess students' problem-solving ability, as shown in Table 2.

Table 2. Problem-solving scoring rubric

Indicator	Description	Score
Understanding the Problem	Clearly identifies known and unknown information; rewrites the problem accurately; recognizes relevant circle elements	0–4
Planning a solution strategy	Selects an appropriate and logical strategy/formula; constructs a supportive diagram or mathematical model	0–4
Implementing the strategy	Executes steps systematically; performs accurate calculations; applies correct procedures to reach the solution	0–4
Reviewing the results	Checks the result; provides logical justification; states a correct and meaningful conclusion	0–4

Procedures

The research was carried out through three main stages, namely:

1. Preparation Stage

Develop PMRI-based learning tools integrated with Augmented Reality (AR) media, develop problem-solving ability test instruments based on Polya stages, and conduct validation by mathematics education experts and subject teachers.

2. Implementation Stage

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This stage begins with a pretest to determine students' initial problem-solving abilities. Next, AR-assisted PMRI based learning is implemented over four sessions. The learning process begins with the presentation of a real-world context, followed by a visual exploration through AR, group discussions, and reflection on the learning outcomes.

3. Analysis Stage

After the entire learning process was completed, students were given a posttest with indicators and difficulty levels equivalent to the pretest. Pretest and posttest data were then collected for statistical analysis to test the research hypotheses.

Analysis

The data obtained from the pretest and posttest results were analyzed using parametric statistics with the help of SPSS software version 26. The analysis was carried out in two stages, namely:

1. Normality Test

This was done using the Shapiro–Wilk test, because the sample size was less than 50. The aim was to determine whether the data were normally distributed.

- **H_0:** The data are normally distributed.
- **H_1:** The data are not normally distributed.
- **Decision rule:** Accept H_0 if the significance value > 0.05.

2. Hypothesis Testing

After the data were declared normally distributed, a paired sample t-test was conducted to see the average difference between the pretest and posttest scores.

- **H_0:** There is no significant difference between the pretest and posttest scores (no effect).
- **H_1:** There is a significant difference between the pretest and posttest scores (there is an effect).
- **Decision rule:** Reject H_0 if Sig. (2-tailed) < 0.05.

This analysis aims to determine whether the application of AR-assisted PMRI-based learning has a significant influence on improving students' problem-solving abilities.

III. Results and Discussion

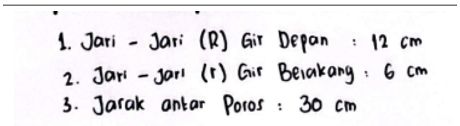
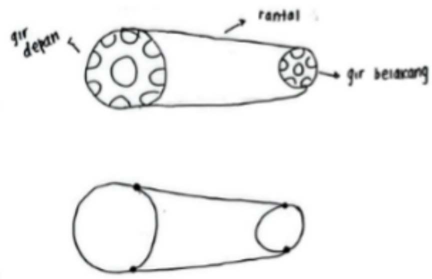
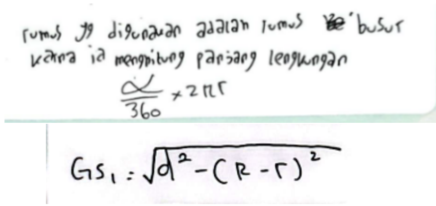
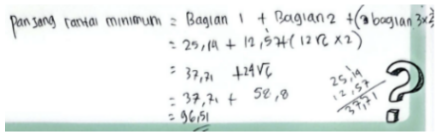
Preparation and Implementation Stage

The initial stage of the research began with the development of learning tools based on Indonesian Realistic Mathematics Education (PMRI) integrated with Augmented Reality (AR) media. The tools developed included teaching modules, student activity sheets, and instruments to assess problem-solving ability. Mathematics education experts and subject teachers carried out validation to ensure the suitability of the content and the integration between the context and the AR media used. The research was conducted in grade XI of SMA Srijaya Negara Palembang for four meetings. Each meeting consisted of introductory, core, and closing activities by implementing PMRI learning steps. In the preparation stage, the researcher developed a PMRI-based learning design integrated with Augmented Reality (AR) by mapping each learning objective into contextual activities that encourage students to actively explore, represent, and reflect on mathematical ideas. Figure 1 shows the activity sheets used in the treatment process.

Figure 1. PMRI based LKPD assisted by AR

Based on Figure 1, the learning activity is centered on the Bicycle Chain Gear context so that students can identify and model the relationships between circle elements. During this stage, students are introduced to the context through AR visualization of bicycle gears, observe the relationship between the front and rear gears, and discuss how the movement can be represented mathematically. Student activity sheets direct them to make observations, create a circle model, connect two circles with tangents, and apply related geometric concepts. Each stage is structured according to Polya's problem-solving stages and PMRI characteristics.

Table 3. Learning activities

Learning Goal	Learning Activities	Problem Solving Behaviors
Students can identify the elements of a circle to solve contextual problems about bicycle gears.	**Activity 1: Understanding Contextual Problems** Students observe the Augmented Reality visualization of bicycle chain gears and describe the parts and relationships shown.	**Activity 1: Understanding Contextual Problems** Students identify given information, recognize relevant data, and restate the contextual problem in their own words.
		
	Activity 2: Modelling in a circular representation Students draw two circles as the front and rear gears and connect them with a straight line as a common tangent based on the AR model.	**Activity 2: Modelling in a circular representation** Students construct visual representations of the problem and link real-world elements to mathematical models.
		
Students can solve problems related to the common tangent of two circles.	**Activity 3: Formulating assumptions and strategies** Students write their predictions and strategies by identifying which geometric properties will help solve the problem.	**Activity 3: Formulating assumptions and strategies** Students select appropriate mathematical principles, create assumptions, and plan steps for solving the tangent problem.
		
	Activity 4: Implementing the strategy Students calculate the total length of the common tangent between two circles using the formula derived from their observations.	**Activity 4: Implementing the strategy** Students perform mathematical procedures accurately to reach solutions, adjusting them as necessary based on their reasoning.
		
	Activity 5: Reflection and Conclusion Students compare results, discuss differences, and conclude which	**Activity 5: Reflection and Conclusion** Students evaluate their own and peers' reasoning, reflect on the process, and

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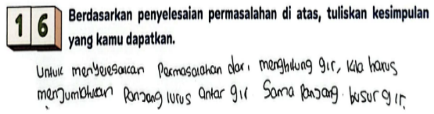
Learning Goal	Learning Activities	Problem Solving Behaviors
	strategy was most effective in solving the tangent problem.	verify the correctness of their solution.
	 16 Berdasarkan penyelesaian permasalahan di atas, tuliskan kesimpulan yang kamu dapatkan. Untuk menyelesaikan permasalahan dari menghitung gir, kita harus menjumlahkan panjang lurus antar gir sama panjang busur gir.	

Description of the Learning Process

Learning is carried out through five worksheet activities that refer to Polya's steps and focus on the topic of the outer common tangent of two circles in the context of a bicycle chain. Augmented Reality (AR) media is used to display the relationship between two gears in real time so that abstract concepts can be visualized in a concrete and engaging way.

Activities 1 and 2 support the problem understanding indicator. The teacher displays an AR gear and asks, "What problem are you going to solve?" "What information do you have?", and "How is the chain positioned in relation to the two gears?". Through the AR, students can see two circles connected by the chain and realize that the chain represents an external common tangent. This visualization helps students identify important information, geometric elements, and their relevance to real-world situations.

Activity 3 focuses on developing strategies. The teacher asks, "What is the central angle formed by the chain at each gear?" and "What formula is used to calculate the arc length?" By observing the AR model, students can estimate the parts of the chain that are arcs and tangents, then formulate a strategy for calculating the minimum total chain length by combining the concepts of arc length and external tangents.

Activity 4 develops indicators for implementing the strategy. Students calculate two straight chain segments (tangents) and two curved chain segments (arcs) and then add them together. The teacher guides by asking, "Do the calculation results match the chain positions in the AR?" AR assistance enables students to verify the accuracy of the model and calculation results visually.

Finally, Activity 5 emphasizes indicators for evaluating results. Students answer reflective questions such as, "Is there another way to determine the length of the chain?" and "Why are the results different between groups?" By reviewing the AR display, students compare the effectiveness of strategies and draw conclusions based on logic and visual evidence.

Overall, student worksheet based questions and AR visualizations help students systematically explore the problem-solving process, understand the context, design strategies, carry out calculations, and evaluate the results, so that mathematical thinking skills and understanding of the concept of external common tangent lines develop meaningfully.

Normality Test Results

A normality test was conducted to ensure that the pretest and posttest data were normally distributed so that they could be analyzed using parametric tests. Based on the Shapiro–Wilk test, the significance values for the pretest and posttest were 0.084 and 0.309, respectively. Both values were greater than 0.05, indicating that the data were normally distributed. Table 2 below shows the complete results of the normality test for students' problem-solving ability data.

Table 4. Shapiro-Wilk normality test

	Statistic	*df*	*Sig.*	*Note*
Pretest	0.946	35	0.084	Normally Distributed
posttest	0.964	35	0.084	Normally Distributed

The results in Table 4 show that both data groups meet the assumption of normality. This indicates a stable data distribution and is suitable for use in subsequent hypothesis testing using the paired sample t-test.

Paired Sample t-Test Results

After confirming that the data were normally distributed, a paired sample t-test was conducted to determine whether there was a statistically significant difference between the pretest and posttest results. The analysis was conducted using SPSS version 26 with a significance level of 0.05. The results of the paired sample t-test are shown in Table 3 below.

Table 5. Paired sample t-Test

	Mean	*SD*	*Mean Difference*	*SD Difference*	*T*	*df*	*Sig.(2-tailed)*
Pre-test	19.37	11.98	-47.14	2.6	-23.053	35	< 0.001
Post-test	66.51	9.38				35	

Based on Table 5, the analysis results show an average pretest score of 19.37 and an average posttest score of 66.51, with a difference in increase of 47.14 points. The t-value obtained was -23.053 with a Significant P-Value. (2-tailed) <0.001. Based on the testing criteria, because the significance value is less than 0.05, then H_0 is rejected and H_1 is accepted. This means that there is a significant difference between the pretest and posttest results. It can be seen that there is a significant difference between the average scores before and after treatment. This shows that the implementation of AR-assisted PMRI-based learning has a positive influence on improving students' mathematical problem-solving abilities.

Discussion

The results of the study indicate that the PMRI-based learning design assisted by Augmented Reality (AR) has a significant influence on improving students' mathematical problem-solving abilities. This is indicated by the significant difference in the average pretest and posttest scores, from 19.37 to 66.51, as well as the results of the t-test with a Significant P-value. (2-tailed) value <0.001. This increase indicates that the change did not occur by chance, but rather was a direct result of the applied learning design.

The AR-assisted PMRI-based learning design was developed by adapting contextual and experiential mathematics learning stages to meet the needs of students. PMRI emphasizes guided reinvention through real-world contexts (Lumahu, Tilaar & Salajang, 2025), while AR media provides visual and interactive support for the concepts being studied (Wiliyanti, Ayu, Noperi & Suryani, 2024). The integration between the two creates a learning environment that allows students to experience, explore, and construct mathematical knowledge in a meaningful way (Komarudin, 2025; Sutrisno & Hamzah, 2024).

In this design, learning is no longer one-way, but instead encourages students to actively understand the context, visualize mathematical models through AR (Komarudin, 2025; Ramadona, Agustiani, Zahra & Putri, 2023), and re-examine their understanding through discussion. This approach directly develops critical and reflective thinking skills, which are core to problem-solving abilities. The AR-assisted PMRI design also provides students with the opportunity to simultaneously link concrete and abstract representations, thereby strengthening conceptual understanding and reducing common misconceptions about mathematics (Ambarita, Sinuhaji, Hasibuan, & Simanullang, 2025; Putri, Hafiza, Ambarita, Nabilah & Suwanto, 2025).

The significant improvement in post-test results demonstrates that the developed learning design effectively integrates theory and practice. The use of real-world contexts makes the learning process more relevant to students' lives, while AR media support improves students' attention, motivation, and spatial abilities in understanding mathematical objects. This aligns with the findings of the study Aditya et al. (2022) dan Nindiasari et al. (2024), which states that AR media plays an important role in increasing cognitive engagement and learning outcomes through interactive visualization.

Theoretically, the success of AR assisted PMRI design also emphasizes that knowledge is constructed through social interactions and meaningful experiences. In the context of this research, the AR-assisted PMRI learning design creates a learning situation that places students at the center, with the teacher acting as a facilitator who provides scaffolding through guidance and visualization (Ambarita et al., 2025; Komarudin, 2025). The process encourages students to go through Polya's four stages: understanding the problem, planning a strategy, implementing the solution, and checking the results in a structured manner.

Thus, the primary influence of AR-assisted PMRI-based learning design lies in increasing students' mental activity (Putri et al., 2025). Students not only receive information, but also conceptualize, compare, and validate their own problem-solving strategies. This process fosters deeper understanding and enhances their ability to address various types of mathematical problems. The results of this study confirm that AR-assisted PMRI design has a significant impact not only on learning outcomes but also on student learning processes. The application of AR within the PMRI framework transforms conventional, abstract learning into a visual, contextual, and collaborative learning experience (Putri et al., 2025; Sutrisno & Hamzah, 2024). Therefore, this learning design can serve as an alternative model to enhance the quality of mathematics learning and foster students' higher-order thinking skills in the digital era.

IV. Conclusion

The results of the study indicate that the learning design based on Indonesian Realistic Mathematics Education (PMRI) assisted by Augmented Reality (AR) has a significant effect on improving the mathematical problem-solving abilities of class XI students of SMA Srijaya Negara Palembang. This is evidenced by the difference in the average pretest score of 19.37 and posttest of 66.51, with a difference in increase of 47.14 points. The t value = -23.053 and Sig. (2-tailed) <0.001 (<0.05) indicates that the increase in students' abilities occurred significantly and consistently after participating in learning using the PMRI-based learning design assisted by AR.

These improvements demonstrate that the implementation of the PMRI–AR learning design is capable of creating a contextual and interactive learning experience. The PMRI approach helps students understand concepts through real-world situations, while AR media visualizes abstract concepts into concrete, easily understood forms. The integration of the two encourages active student engagement in understanding problems, planning strategies, and examining solutions, thereby enhancing logical, reflective, and creative thinking skills in solving mathematical problems.

The findings of this study indicate that the PMRI-based learning design assisted by Augmented Reality (AR) is effective in significantly improving students' mathematical problem-solving abilities. This design is proven to create more contextual and engaging learning and facilitate the understanding of abstract concepts through interactive visualization. Based on these results, it is recommended that mathematics teachers begin integrating the PMRI approach with AR-based media as an innovative learning approach, and that future researchers test the effectiveness of similar designs on different materials and educational levels to expand the application and validity of the findings.

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