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The Effect of Problem-Based Learning Model Assisted by Augmented Reality and Digital Literacy on Mathematical Problem-Solving Ability of Fifth Grade Elementary School Students

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ABSTRACT: This study aims to analyze the effect of the Problem Based Learning (PBL) model assisted by Augmented Reality (AR) on the mathematical problem-solving ability of fifth-grade students and to analyze the effect of digital literacy and the interaction between learning models and digital literacy on mathematical problem-solving ability. This study uses a quantitative approach with a nonequivalent pretest–posttest control group quasi-experimental design and a 2 × 2 factorial design. The research subjects were 56 fifth-grade students of SDN Tanah Kalikedinding I/251 Surabaya who were divided into an experimental group with the AR-assisted PBL model and a control group with conventional learning. Data collection was carried out using a mathematical problem-solving ability test and a digital literacy test. Data analysis was carried out using Independent Samples t-Test and two-way analysis of variance (ANOVA). The results showed that the AR-assisted PBL model had a significant effect on mathematical problem-solving ability, with a t value = 3.264, df = 54, and Sig. (2-tailed) = 0.002. Digital literacy also has a significant effect on mathematical problem-solving ability, with a t-value of 4.737, df = 46.158, and Sig. (2-tailed) = 0.000. The results of the two-way ANOVA show that the learning model has a significant effect with F = 12.046, Sig. = 0.001, and partial eta squared = 0.188; digital literacy has a significant effect with F = 32.571, Sig. = 0.000, and partial eta squared = 0.385; and there is a significant interaction between the learning model and digital literacy with F = 12.908, Sig. = 0.001, and partial eta squared = 0.199. Thus, AR-assisted PBL has a significant effect on mathematical problem-solving ability, and this effect interacts with the level of digital literacy of stude

KEYWORDS: augmented reality, digital literacy, elementary school, mathematical problem-solving skills, mathematics learning, problem-based learning.

INTRODUCTION

Mathematics learning in elementary schools is expected to develop not only procedural fluency, but also students' abilities to understand situations, identify relevant information, choose appropriate strategies, implement procedures, and evaluate the reasonableness of the results obtained (Fasihah et al., 2026). These competencies become increasingly important when students face contextual problems that cannot be solved simply by applying memorized formulas. Therefore, a learning environment that positions students as active problem solvers is needed to strengthen mathematical thinking and problem-solving skills.

Problem-Based Learning (PBL) provides a learning structure that begins with an authentic or contextual problem, then guides students to investigate, discuss, formulate strategies, and communicate solutions (Maryani et al., 2025). This model is relevant in mathematics learning because problem situations can serve as a starting point for concept formation, rather than simply being practiced after direct presentation of the material. A number of studies also report the application of PBL combined with Augmented Reality (AR) in mathematics learning and problem solving at the elementary school level (Rihayati et al., 2023; Sulhaliza et al., 2025).

AR can complement PBL by providing interactive visual representations of objects that are difficult to observe directly. In geometry learning, students can observe and explore three-dimensional representations, thereby connecting abstract mathematical properties with more concrete visual experiences (Akbar et al., 2025). Previous research has shown that AR-assisted PBL can contribute to mathematics learning and problem-solving skills, although some studies have focused on single-group design or learning outcomes without considering differences in students' digital literacy (Wilandari et al., 2024; Ihwan & Rusnilawati, 2025).

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Digital literacy is relevant because technology-assisted learning does not solely depend on the availability of digital devices or media. Students also need to be able to operate digital devices, interpret information presented in digital environments, communicate and collaborate appropriately, and use technology in a targeted manner. In AR-assisted PBL learning, these competencies can influence students' effectiveness in interacting with digital representations and transforming the information obtained into mathematical problem-solving strategies (Rahmawati et al., 2026). Thus, digital literacy can not only be viewed as a learning outcome, but also as a student characteristic that can influence the effectiveness of technology-based learning.

Based on this review, there is a research gap in studies that simultaneously examine the effect of AR-assisted PBL on mathematical problem-solving skills, taking into account digital literacy levels and the interaction between learning models and digital literacy, particularly in elementary school students. This study aims to fill this gap by examining the effect of AR-assisted PBL, digital literacy, and their interaction on the mathematical problem-solving skills of fifth-grade students at SDN Tanah Kalikedinding I/251 Surabaya in the even semester of the 2025/2026 academic year. Conceptually, the relationship between learning models, digital literacy, and mathematical problem-solving skills in this study is presented in Figure 1.

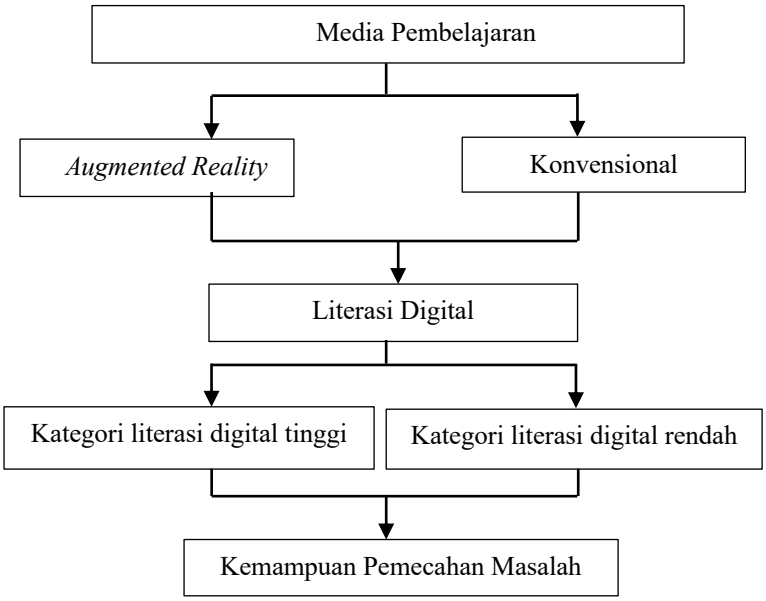


Figure 1. Framework of thinking

Figure 1 shows that a problem-based learning model, aided by augmented reality and digital literacy, can influence problem-solving skills. The application of AR-assisted PBL provides a more contextual and interactive learning experience, encouraging students to actively engage and solve mathematical problems (Rahmawati et al., 2026). Furthermore, digital literacy supports the use of technology and information in learning. Therefore, a problem-based learning model, aided by augmented reality and supported by digital literacy, is expected to improve the mathematical problem-solving skills of fifth-grade students at SDN Tanah Kalikedinding 1 Surabaya.

Based on this framework, the authors believe that this study is necessary to determine the effect of an AR-assisted PBL learning model, digital literacy, and their interaction on fifth-grade elementary school students' mathematical problem-solving skills. The following hypotheses are proposed.

The first hypothesis: There is a significant influence of the Problem-Based Learning (PBL) model assisted by Augmented Reality (AR) on the mathematical problem-solving abilities of fifth-grade elementary school students.

The second hypothesis: There is a significant influence of digital literacy on the mathematical problem-solving abilities of fifth-grade elementary school students.

The third hypothesis: There is a significant interaction between the Problem-Based Learning (PBL) model assisted by Augmented Reality (AR) and digital literacy on the mathematical problem-solving abilities of fifth-grade elementary school students.

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The results of this study are expected to contribute to the development of mathematics learning in elementary schools, particularly as a consideration for teachers in implementing the AR-assisted PBL model and developing students' digital literacy as an effort to improve mathematical problem-solving abilities.

MATERIALS AND METHODS

Study design and setting

This study used a quantitative approach with a nonequivalent pretest–posttest control group quasi-experimental design and a 2 × 2 factorial design. The first factor was the learning model, consisting of AR-assisted PBL and conventional learning. The second factor was students' digital literacy, categorized as high and low. The dependent variable in this study was mathematical problem-solving ability, measured after the learning treatment (Maryani et al., 2025). The research design is presented in Figure 2.

Kemampuan Literasi Digital / Model Pembelajaran	Tinggi	Rendah
Model pembelajaran PBL-AR	X_1	X_2
Model pembelajaran konvensional	X_3	X_4

Figure 2. Quasi-Experimental Factorial Design

Students and Sample

The research population was fifth-grade students at SDN Tanah Kalikedinding I/251 Surabaya. Two established fifth-grade classes, totaling 56 students, were selected as the sample. One class was designated as the experimental group, receiving AR-assisted PBL, while the other class served as the control group, receiving conventional mathematics instruction. The factorial distribution consisted of 14 experimental students with high digital literacy, 14 experimental students with low digital literacy, 13 control students with high digital literacy, and 15 control students with low digital literacy.

Learning Implementation

The treatment was implemented through mathematics instruction on spatial figures, specifically the concepts of cubes and cuboids, as well as problems related to volume. In the experimental class, students were given contextual problems, organized into groups, identified and investigated information in the problems, used AR-assisted representations to observe and explore three-dimensional objects, developed solution strategies, and presented and evaluated their solutions (Anggiani et al., 2025). The control class received conventional instruction through teacher explanations, examples, guided practice, and practice problems. Learning was carried out over 9 meetings with a time allocation of 2 x 35 minutes for each meeting for both the experimental and control classes.

Data Collection and Measurement Procedures

Research data was collected using a digital literacy test and a mathematical problem-solving ability test. The digital literacy instrument was used to obtain data on students' abilities to understand, use, and utilize digital information and technology in the learning process (Qurniasty et al., 2025). The instrument consisted of five questions, with scores adjusted based on established digital literacy indicators. The digital literacy scores were then used to categorize students into high and low digital literacy categories. Students with scores between 11 and 20 were categorized as high digital literacy, while those with scores between 1 and 10 were categorized as low digital literacy. Meanwhile, the mathematical problem-solving ability test was used to obtain data on students' abilities to understand problems, plan problem-solving strategies, implement strategies, and review their mathematical problem-solving results (Rahmawati et al., 2026). Both instruments were developed by researchers based on the indicators of each variable and then tested for validity and reliability before being used in the study (Wahyuni et al., 2024).

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Table I. Results of Validity and Reliability Tests of Research Instruments

No.	Variabel	Number of items	Koefisien korelasi Pearson	Koefisien Alpha Cronbach	Information
1	Digital Literacy	5	0,769–0,916	0,815	Valid and Reliabel
2	Problem-solving skills	5	0,652–0,954	0,807	Valid and Reliabel

The digital literacy instrument was used to measure students' ability to understand, use, and utilize digital information and technology in the learning process. The digital literacy instrument consisted of five items structured according to the digital literacy indicators used in the study. Validity tests showed that the five items had Pearson correlation values, with total scores ranging from 0.769 to 0.916, with a significance level of 0.000 <0.05, thus all items were declared valid. Reliability tests showed a Cronbach's Alpha coefficient of 0.815, thus the digital literacy instrument was deemed reliable.

A mathematical problem-solving ability test was used to measure students' ability to understand and solve mathematical problems. The test consisted of five items structured according to the indicators of mathematical problem-solving ability. Validity tests showed that the five items had Pearson correlation values, with total scores ranging from 0.652 to 0.954, with a significance level of 0.000 <0.05, thus all items were declared valid. The results of the reliability test showed a Cronbach's Alpha coefficient value of 0.807, so the mathematical problem-solving ability test was declared reliable.

Data Analysis

The research data, consisting of the Problem-Based Learning (PBL) model assisted by Augmented Reality (AR), digital literacy, and mathematical problem-solving skills, were analyzed using parametric statistical techniques with IBM SPSS Statistics. Prior to analysis, the data were tested for normality using the Kolmogorov-Smirnov method and for homogeneity of variance. Data were declared normally distributed if the significance value was >0.05, and homogeneous if the significance value was >0.05 (Hartono et al., 2026). The first and second hypotheses were tested using the Independent Samples t-test, while the third hypothesis was tested using a two-way ANOVA at a significance level of 0.05.

Table II. Results of the Normality Test for Research Data Distribution

No.	Data	Kolmogorov-Smirnov	Asymp. Sig. (2-tailed)	Information
1	Eksperimen	0,079	0,200	Normally distributed
2	Control	0,113	0,200	Normally distributed

Table III. Results of the Homogeneity of Variance Test

Data	Levene's Test (F)	Sig.	Keterangan
Mathematical Problem-Solving	1,675	0,201	Homogen

Based on the results of the normality test in Table II, the Kolmogorov-Smirnov significance value for the experimental and control classes was 0.200 > 0.05, respectively. Thus, the mathematical problem-solving ability data in both classes were normally distributed. Meanwhile, the homogeneity test in Table III yielded a Levene's Test value of 1.675 with a significance value of 0.201 > 0.05. Therefore, the variance of the mathematical problem-solving ability data in the experimental and control classes was deemed homogeneous. Based on the results of the normality and homogeneity tests, the research data met the requirements for parametric statistical analysis using the Independent Samples t-Test and Two-Way ANOVA.

RESULTS

Data analysis was conducted to determine the effect of the Problem-Based Learning (PBL) model assisted by Augmented Reality (AR) on mathematical problem-solving skills based on students' digital literacy levels. The study involved 56 fifth-grade students, consisting of an experimental group with AR-assisted PBL learning and a control group with conventional learning.

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Table IV. Descriptive Statistics

Model Pembelajaran	Literasi Digital	N	Mean	SD
AR-assisted PBL	high	14	87,07	6,967
AR-assisted PBL	Low	14	69,07	6,195
Conventional	High	13	75,00	7,472
Conventional	Low	15	68,47	7,269

Table IV shows that the highest average mathematical problem-solving ability was found in the AR-assisted PBL group with high digital literacy (M = 87.07; SD = 6.967). The lowest average was found in the conventional learning group with low digital literacy (M = 68.47; SD = 7.269). To determine differences in mathematical problem-solving ability based on learning model and digital literacy level, an Independent Samples t-Test was conducted. The test results are presented in Table V.

Table V. Independent Samples t-Test Results

Variabel	t	df	Sig. (2-tailed)	Mean Difference
Learning Model	3,264	54	0,002	7,964
Digital Literacy	4,737	46,158	<0,001	10,815

The results in Table V show a significant difference in mathematical problem-solving abilities between students who received AR-assisted PBL and those who received conventional learning ($t = 3.264$; $p = 0.002$). Furthermore, there was a significant difference between students with high and low digital literacy ($t = 4.737$; $p < 0.001$). Next, the simultaneous effects of the learning model and digital literacy, as well as their interaction, were analyzed using a two-way ANOVA. The results are presented in Table VI.

Table VI. Two-Way ANOVA Results

Source of Variation	df	F	Sig.	Partial Eta Squared
Learning Model	1	12,046	<0,001	0,188
Digital Literacy	1	32,571	<0,001	0,385
Learning Model × Digital Literacy	1	12,908	0,001	0,199
Corrected Model	3	19,047	<0,001	0,524

The results of the Two-Way ANOVA showed that the learning model had a significant effect on mathematical problem-solving ability ($F = 12.046$; $p < 0.001$). Digital literacy also had a significant effect on mathematical problem-solving ability ($F = 32.571$; $p < 0.001$). In addition, there was a significant interaction between the learning model and digital literacy ($F = 12.908$; $p = 0.003$). The Partial Eta Squared value of 0.199 indicated an interaction effect between the learning model and digital literacy on mathematical problem-solving ability.

DISCUSSION

Research findings indicate that the implementation of Problem-Based Learning (PBL) assisted by Augmented Reality (AR) significantly impacts students' mathematical problem-solving abilities. Independent Samples t-Test results showed a t-value of 3.264 with a df of 54 and a significance level of $0.002 < 0.05$, with a mean difference of 7.964. These results indicate a difference in mathematical problem-solving abilities between students who received AR-assisted PBL learning and those who received conventional learning. This finding aligns with research (Fasihah et al., 2026), which demonstrated that the implementation of PBL combined with AR significantly impacts the problem-solving abilities of elementary school students. This integration was also reported to increase student engagement, help visualize abstract concepts, and support the development of cognitive skills. These findings extend previous research by considering digital literacy as a factor interacting with the learning model. Previous research on the implementation of PBL combined with AR in mathematics learning. Rihayati et al. (2023) reported that AR-assisted PBL was relevant for improving fifth-grade elementary school students' mathematical problem-solving skills, while Sulhaliza et al. (2025) reported positive results from implementing AR-assisted PBL in elementary school mathematics learning. This study extends these findings by using a factorial design that also considers students' digital literacy.

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The impact of AR-assisted PBL can be understood through the complementary roles of learning models and technology. PBL organizes learning through problems that encourage students to identify information, discuss approaches, develop strategies, test solutions, and evaluate results. Meanwhile, AR provides interactive visual representations that can help students observe and explore mathematical objects more concretely. Previous research also shows that AR integration can enrich the learning experience by presenting information in the form of interactive visual elements. When these two approaches are combined, technology functions not only as a medium for presenting material but also as part of the inquiry process in solving problems. This is relevant for geometric shapes because students need to connect visual representations with the characteristics and properties of three-dimensional objects.

Digital literacy also showed a significant influence on mathematical problem-solving abilities. The Independent Samples t-Test results obtained a t value of 4.737 with df = 46,158 and a significance level of 0.000 < 0.05, with a mean difference of 10.815. These results indicate a difference in mathematical problem-solving abilities between students with high and low digital literacy levels. This finding is in line with (Caponera et al., 2026) which shows that digital literacy contributes significantly to students' mathematical performance. Students with higher digital literacy abilities tend to achieve better mathematics results. Students with better digital literacy abilities have greater readiness to operate devices, understand digital information, and utilize technology in the learning process. In AR-assisted learning, these abilities are important because students need to interact with digital representations and use them to support the process of understanding and solving mathematical problems. This finding is in line with Suryani et al. (2024) showed that mathematical problem-solving abilities differed according to students' digital literacy levels. These results support the hypothesis that digital literacy is a relevant characteristic in supporting the mathematical problem-solving process.

Another important finding is the interaction between learning models and digital literacy on mathematical problem-solving abilities. The results of the two-way ANOVA showed an F value = 12.908 with a significance of 0.001 < 0.05 and a partial eta squared of 0.199. These results indicate that the influence of learning models on mathematical problem-solving abilities differs according to students' digital literacy levels. Descriptively, the experimental group with high digital literacy obtained an average problem-solving ability of 87.07, while the experimental group with low digital literacy obtained an average of 69.07. In the control group, students with high digital literacy obtained an average of 75.00, while the group with low digital literacy obtained an average of 68.47. This pattern shows that the implementation of AR-assisted PBL provides stronger benefits for students with high digital literacy. This finding indicates that the success of technology-based learning depends not only on the quality of the learning model and media, but also on the readiness of students to utilize the technology. The interaction findings in this study indicate that the effectiveness of AR-assisted PBL does not stand alone, but is related to the characteristics of the students participating in the learning. These findings align with those of Diana et al. (2026), who demonstrated an interaction effect in technology-assisted PBL learning on mathematical problem-solving abilities. These results reinforce the view that technology integration in PBL needs to consider student characteristics and readiness to optimally benefit from the learning process.

From a practical perspective, teachers implementing AR-assisted PBL need to integrate digital literacy support into the learning process. Students can be provided with guidance in accessing AR content, operating and manipulating digital objects, interpreting visual information, and using technology to support the problem-solving process. This approach aligns with previous research findings showing that the use of AR in learning can provide a more interactive learning experience and help students explore object representations more visually. Therefore, strengthening digital literacy needs to be positioned as a supporting element in the implementation of technology-based learning, not simply as an additional skill.

This study has several limitations. First, the sample consisted of only two fifth-grade classes from one elementary school, each with 56 students. Therefore, generalization of the results requires caution. Second, digital literacy was categorized into high and low groups based on predetermined cutoff points, so this categorization does not fully reflect the multidimensional characteristics of digital literacy. Third, the study focused on mathematical problem-solving skills in spatial geometry, with nine sessions of treatment. Therefore, further research could involve a larger number of schools and students, examine the dimensions of digital literacy more specifically, and test the application of AR-assisted PBL to different mathematics materials and learning durations. The recommendation to expand the scope of the material and involve a larger sample is also in line with the direction of previous research on the development of AR-assisted learning.

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CONCLUSION

Based on the results of the data analysis and discussion of the study, it can be concluded that the application of the Augmented Reality (AR)-assisted Problem-Based Learning (PBL) learning model significantly impacted students' mathematical problem-solving abilities. Students who received AR-assisted PBL learning demonstrated better mathematical problem-solving abilities than those who received conventional learning.

Furthermore, digital literacy significantly impacted mathematical problem-solving abilities. Students with high levels of digital literacy demonstrated better mathematical problem-solving abilities than those with low levels. This finding indicates that digital literacy skills are a factor supporting students in understanding information, using learning technology, and solving mathematical problems.

The results also showed a significant interaction between the AR-assisted PBL learning model and digital literacy on mathematical problem-solving abilities. Thus, the effectiveness of AR-assisted PBL in improving mathematical problem-solving abilities is closely related to students' digital literacy levels. AR-assisted PBL learning provides more optimal results, especially for students with high digital literacy. Overall, the integration of PBL, AR technology, and strengthening digital literacy can be an effective learning alternative to support the development of elementary school students' mathematical problem-solving abilities.

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