

Can Problem-Based Learning with Augmented Reality Enhance Science Literacy and Learning Motivation? Development of a Model for Third-Grade Elementary Students

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Abstract

Science literacy among elementary school students in Indonesia remains relatively low, while the integration of problem-based learning (PBL) and augmented reality (AR) at the early grade level has received limited empirical attention. This study aims to develop and test an AR-assisted PBL model to improve science literacy and learning motivation among third-grade elementary school students. The study employed an adapted Borg and Gall Research and Development model comprising initial product development and expert validation, instrument validity and reliability testing, three stages of product testing (limited, main field, and operational trials), and product revision at each stage. The participants were 75 third-grade students, with 25 students in each trial stage. Data were analyzed using paired t-tests and normalized N-Gain. Expert validation indicated that the model was feasible, with validity scores of 78.8% from media experts and 76.2% from material experts. Across all trial stages, science literacy increased significantly ($p < 0.001$) moderate N-Gain. Learning motivation also increased significantly, although gains ranged from low to moderate. Product practicality ranged from 74.6% to 82.3%. These findings demonstrate that AR-assisted PBL is an effective and practical approach for science learning in third-grade elementary schools and extend empirical evidence on PBL-AR integration in early-grade Indonesian elementary education.

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INTRODUCTION

Science literacy is an important competency for learners to participate intelligently in the economic and civic life of the 21st century. However, the science literacy achievement of Indonesian students still shows a serious gap. The Programme for International Student Assessment (PISA) 2022 recorded Indonesia's science score of 383, far below the OECD average of 485 (OECD, 2023). This condition shows the need to strengthen science learning from the elementary school level, especially through an approach that is able to involve students in the

process of investigation and problem-solving. One of the approaches that is growing is augmented reality (AR), which based on meta-analysis shows a positive effect on the learning motivation of K-12 students with an effect size $g = 0.803$ from 45 experimental studies (Na & Yun, 2024) as well as improving academic achievement in science learning (Kalemkuş & Kalemkuş, 2022). When combined with problem-based learning (PBL), AR also reported to produce better academic achievement and reflective thinking skills than PBL without AR (Arici & Yilmaz, 2023). The findings show the potential for integration of AR and PBL, but their application to early elementary school science learning, especially in Indonesia, is still limited.

These limitations are important because elementary school is the initial stage of the formation of scientific reasoning. Research in Indonesia shows that students' low science literacy is related to the limitations of innovative and contextual learning methods and the lack of student involvement in direct science investigation (Suparya et al., 2022). A number of studies show that AR can provide benefits to elementary school students. The integration of AR with concept maps improves science learning outcomes (Chou et al., 2022), while AR-assisted learning is reported to increase learning outcomes, motivation, and creativity, especially in low-grade students (Yousef, 2021). However, the effectiveness of AR is not universal. Meta-analyses show that learner characteristics and intervention design can influence the magnitude of AR's effects on science learning (Xu et al., 2022). In addition, most AR and PBL research still focuses on students in grades four through six or high school, so the evidence on its application to third grade elementary school students is limited.

The existing literature shows that the effectiveness of AR is also not completely consistent. Meta-analyses found the positive effects of AR on science academic motivation and achievement, while the integration of AR with active pedagogical structures such as PBL can strengthen reflective thinking and problem-solving abilities (Na & Yun, 2024; Kalemkuş & Kalemkuş, 2022; Arici & Yilmaz, 2023). However, the effect differs between motivational components. Within the framework of ARCS, AR more consistently increases attention and self-confidence than satisfaction (Prasetya et al., 2024). On the other hand, recent research suggests that increased engagement and visual appeal through AR is not always followed by improved learning outcomes, as visual and interactive elements can increase cognitive load without resulting in commensurate conceptual processing (Bhat et al., 2025). These differences are reinforced by the findings that intervention design, learning content, and learner characteristics moderate the effectiveness of AR (Xu et al., 2022). Thus, it is still unclear how AR integrated with PBL can affect science literacy and learning motivation at the same time, especially in elementary school early grade students.

Theoretically, the integration of PBL and AR can be explained through three complementary foundations. PBL is rooted in constructivism which views knowledge as a result of construction through the experience of solving authentic problems, so that the process of problem identification, evidence search, and explanatory testing can be the basis for the development of science literacy (Hmelo-Silver, 2004). The Cognitive Theory of Multimedia Learning explains that verbal and visual representations are processed through different channels with limited capacity, so three-dimensional visualization through AR has the potential to help students understand abstract phenomena by allocating cognitive resources to active processing (Mayer, 2024). Meanwhile, the ARCS model explains that attention, relevance, confidence, and satisfaction can build learning motivation, with evidence that AR in particular can strengthen

students' attention and confidence (Prasetya et al., 2024). All three perspectives point to complementary mechanisms: PBL provides an authentic problem structure, AR provides visual and interactive representations, while ARCS describes motivational mechanisms that support student engagement. However, most of the theoretical evidence comes from adolescent, college students, or adults, so its application to elementary school third-graders still requires empirical testing.

Based on this synthesis, there are three main gaps in the literature. First, evidence on the effectiveness of PBL-assisted AR on science literacy is still concentrated in students in the fourth grade and above or at the secondary school level (Arici & Yilmaz, 2023; Chou et al., 2022), even though the effectiveness of AR is influenced by the characteristics of learners and the design of the intervention (Xu et al., 2022). Second, research in Indonesia has identified more factors related to low science literacy, such as the limitations of innovative methods and investigative activities, but has not extensively tested PBL-assisted AR as an intervention in elementary school early grades (Suparya et al., 2022). Third, science literacy and learning motivation are more often studied as separate outcomes, while evidence that AR can increase engagement without a commensurate increase in learning outcomes suggests that the two outcomes do not always move simultaneously (Bhat et al., 2025). Therefore, testing is needed that specifically develops and evaluates an integrated learning model in third grade elementary school students in Indonesia with science literacy and learning motivation as outcomes that are tested simultaneously.

This research fills this gap by developing an AR-assisted PBL model designed for elementary school third graders. This is different from previous research that focused on fourth grade and above or higher education levels (Arici & Yilmaz, 2023; Chou et al., 2022), this study places third-grade students as a testing context that has different developmental characteristics. This study also extends the empirical evidence to the Indonesian primary school context, which was previously more researched in terms of diagnosing science literacy problems than testing AR and PBL-based interventions (Suparya et al., 2022). In addition, this study examined science literacy and learning motivation simultaneously to obtain a more comprehensive picture of the effectiveness of the model, especially considering that the relationship between engagement, motivation, and learning outcomes has not always been consistent (Bhat et al., 2025). Thus, the novelty of the research lies in the integration of PBL and AR in a model specifically aimed at elementary school third grade students as well as the simultaneous testing of two learning outcomes.

Based on this gap, this study aims to develop and test an augmented reality-assisted problem-based learning model for elementary school third grade students and analyze its influence on science literacy and learning motivation. In particular, this study examines whether the developed model produces differences in science literacy and learning motivation compared to learning used in comparative conditions. This research also makes a theoretical contribution by examining the relevance of constructivism, Cognitive Theory of Multimedia Learning, and the ARCS model in the context of early grade elementary school students (Hmelo-Silver, 2004; Mayer, 2024; Prasetya et al., 2024). Empirically, this study expands the evidence on the use of AR and PBL for the development of science literacy and learning motivation in the context of Indonesian primary schools. Practically, the developed model can be an alternative for teachers in designing science

learning that integrates problem investigation, concept visualization, and active student engagement.

METHOD

Research Design

This research uses the Borg and Gall model Research and Development (R&D) approach, which consists of ten standard steps, namely research and initial information collection, planning, initial product development, limited trial, main product revision, main field trial, operational product revision, operational field trial, final product revision, and dissemination and implementation (Husnayayin, Gustina, & Dewi, 2024). This study adapts the ten steps into four operational stages, namely initial product development and expert validation, empirical validity and reliability testing of instruments, gradual product testing, and product revision at each stage. The product developed is in the form of an augmented reality-assisted problem-based learning model for grade 3 elementary school science subjects, with science literacy and learning motivation as variables measured at each stage of the trial. The complete stages of this research and development procedure are illustrated in Figure 1. The augmented reality-assisted problem-based learning model developed in this study follows five syntactic phases, namely orienting students to the problem, organizing students for learning, guiding individual and group investigation, developing and presenting the results of work, and analyzing and evaluating the problem-solving process.

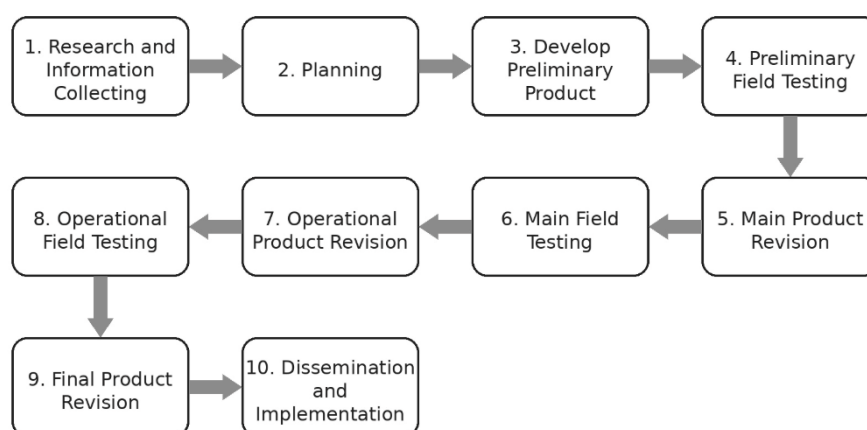


Figure 1. Flow of the Borg and Gall Research and Development Procedure (Borg & Gall, 1983)

Research Subject

This study was conducted at SDN 111 PINDAD, Bandung City. The research subjects involved grade 3 elementary school students in three consecutive trial stages, namely limited trial, main field trial or area test 1, and operational field trial or area test 2. Each stage involved 25 different and non-overlapping students, so that the total subjects in the entire study amounted to 75 students. Details of the composition of the subject are presented in Table 1.

Table 1. Recapitulation of Research Subjects at Each Stage

Research Stage	Number of Subjects (n)	Male	Women
Limited Trial	25	9	16
Main Field Trials (Area 1)	25	13	12
Operational Field Trials (Area 2)	25	12	13

In addition to the test subject, this study involved two experts as product validators, namely one learning media expert and one material expert, who assessed the feasibility of the product before entering the field trial stage.

Research Procedure

The research procedure follows the following stages. First, the initial product development stage includes research and initial information collection, planning, and drafting an augmented reality-assisted problem-based learning model that is in accordance with the characteristics of grade 3 elementary school students.

Second, the expert validation level tests the feasibility of the initial product through the evaluation of two experts using a questionnaire instrument on a scale of 1 to 4 with 10 items of statement. The validation results are used as a basis for product revision before entering the field trial stage.

Third, the validity and empirical reliability test stage of the instrument tested the feasibility of the science literacy test instrument and the learning motivation questionnaire for 25 students, before the instrument was used in the product trial stage.

Fourth, the product trial stage is carried out in three consecutive steps according to the Borg and Gall model, namely limited field testing, main field testing, and operational field testing. Each step is followed by a revision of the product based on the findings in the previous step, before the product is tested on the next group of students. At each stage of the trial, three aspects were measured, namely the effectiveness of the model on science literacy through the design of a pretest posttest in one group, an increase in learning motivation before and after the application of the model, and the practicality of the product according to the perception of students.

Research Instruments

Scientific Literacy Instrument

Scientific literacy was measured using a ten-item essay test developed based on the scientific literacy framework proposed by the Programme for International Student Assessment (PISA). According to this framework, scientific literacy encompasses three core competencies: explaining scientific phenomena, evaluating and designing scientific inquiry, and interpreting data and evidence scientifically (OECD, 2023). The test focused on eye anatomy and eye health and assessed students' ability to apply scientific knowledge, use inquiry processes, and interpret scientific evidence when solving problems encountered in everyday life. The operationalization of scientific literacy indicators is presented in Table 3.

Table 3. Scientific Literacy Indicators and Scoring Scheme

Dimension	Indicator	Number of Items
Explaining scientific phenomena	Identifying the parts of the eye based on pictures or models	1
	Explaining the functions of the cornea, iris, pupil, lens, and retina	1
	Explaining the process of vision using age-appropriate scientific concepts	1
	Relating eye structures to their functions in the visual process	1
Evaluating and designing scientific inquiry	Identifying problems related to eye health in daily life	1
	Determining ways to investigate factors affecting eye health	1
	Evaluating appropriate actions to maintain eye health based on scientific principles	1
Interpreting data and evidence scientifically	Interpreting information presented in pictures, diagrams, or tables related to eye health	1
	Analyzing the relationship between daily habits and eye health based on evidence	1
	Using scientific evidence to make decisions regarding proper eye-care practices	1

Responses to the scientific literacy test were assessed using a four-level analytic rubric ranging from 0 to 3, where higher scores indicated higher levels of scientific literacy. The resulting scores were subsequently used as pretest and posttest data to evaluate students' improvement following participation in the AR-assisted Problem-Based Learning activities.

Before being used at the product trial stage, the science literacy test instrument and learning motivation questionnaire were first empirically tested for validity and reliability on 25 students. The validity of the item was tested using the product moment correlation technique by correlating the item score to the total score; The item is declared valid if r is calculated $> r$ table, with r table for $n = 25$ at a significance level of 5% of 0.396. The reliability of the instrument is tested using the Alpha Cronbach coefficient.

Table 4. Results of the Validity Test of Science Literacy Test Questions ($n = 25$)

Question Item	Type	r count	r Table	Remarks
SL 1	Multiple Choice	0,150	0,396	Invalid
SL 2	Multiple Choice	0,400	0,396	Valid
SL 3	Multiple Choice	0,121	0,396	Invalid
SL 4	Multiple Choice	0,280	0,396	Invalid
SL 5	Multiple Choice	0,475	0,396	Valid
SL 6	Multiple Choice	0,376	0,396	Invalid
SL 7	Multiple Choice	0,580	0,396	Valid

Question Item	Type	r count	r Table	Remarks
SL 8	Multiple Choice	0,397	0,396	Valid
SL 9	Multiple Choice	0,527	0,396	Valid
SL 10	Multiple Choice	0,544	0,396	Valid
SL 11	Essay	0,739	0,396	Valid
SL 12	Essay	0,632	0,396	Valid
SL 13	Essay	0,467	0,396	Valid
SL 14	Essay	0,506	0,396	Valid
SL 15	Essay	0,232	0,396	Invalid

Of the 10 multiple-choice questions, 6 items were declared valid (numbers 2, 5, 7, 8, 9, and 10), while of the 5 items of description questions, 4 items were declared valid (numbers 1, 2, 3, and 4). The Alpha Cronbach reliability coefficient for the overall instrument was 0.697, indicating an adequate level of reliability for a science literacy test instrument to be used in the product testing phase. Items that are declared invalid are not included in the final instrument or revised redaction before being used at a later stage.

Learning Motivation Instrument

Learning motivation was measured using a ten-item questionnaire adapted from Keller's ARCS motivational model, which consists of four dimensions: Attention, Relevance, Confidence, and Satisfaction (Keller, 2010). The ARCS model was selected because it provides a comprehensive framework for evaluating students' motivational responses during learning activities. Previous studies have demonstrated that augmented reality learning environments positively influence students' attention, confidence, engagement, and overall learning motivation. Therefore, the ARCS framework served as the theoretical foundation for developing the learning motivation instrument used in this study. The operationalization of the learning motivation indicators is presented in Table 5.

Table 5. Learning Motivation Indicators

Dimension	Indicator	Number of Items	Score
Attention	Paying attention during science learning activities	1	1-4
	Showing interest when using AR-assisted learning media	1	1-4
	Maintaining concentration during learning activities	1	1-4
Relevance	Perceiving science learning as useful in daily life	1	1-4
	Relating eye-health knowledge to personal experiences	1	1-4
Confidence	Feeling confident in identifying eye structures correctly	1	1-4
	Being willing to answer questions during learning activities	1	1-4
	Believing in the ability to complete science learning tasks successfully	1	1-4
Satisfaction	Feeling satisfied with learning achievements	1	1-4

Dimension	Indicator	Number of Items	Score
	Enjoying learning experiences through AR-assisted PBL activities	1	1-4

Responses were measured using a four-point Likert scale consisting of Strongly Disagree, Disagree, Agree, and Strongly Agree. Higher scores indicated stronger learning motivation toward science learning activities. Overall scores and scores for each ARCS dimension were subsequently analyzed to identify students' motivational profiles after participating in the AR-assisted Problem-Based Learning activities.

Table 6. Validity Test Results of Learning Motivation Questionnaire Items (n = 25)

Statement Item	r count	r Table	Remarks
Item 1	0,745	0,396	Valid
Item 2	0,689	0,396	Valid
Item 3	0,310	0,396	Invalid
Item 4	0,376	0,396	Invalid
Item 5	0,587	0,396	Valid
Item 6	0,450	0,396	Valid
Item 7	0,587	0,396	Valid
Item 8	0,543	0,396	Valid

Of the 8 statements, 6 items were declared valid (numbers 1, 2, 5, 6, 7, and 8), while the other 2 items (numbers 3 and 4) were declared invalid and were not included in the final score of the questionnaire. The Alpha Cronbach reliability coefficient of 0.611 shows that the learning motivation questionnaire is reliable and suitable for use at the product trial stage.

Data Analysis Techniques

Data analysis was conducted in four stages: expert validation analysis, instrument quality analysis, effectiveness analysis, and practicality analysis.

First, data obtained from the expert validation questionnaire were analyzed descriptively to determine the validity level of the developed AR-assisted Problem-Based Learning (PBL) model. The validity results were then classified into predetermined feasibility categories.

Second, the quality of the research instruments was evaluated through empirical validity and reliability testing before field implementation. Item validity was examined using Pearson's Product-Moment correlation analysis, while instrument reliability was assessed using Cronbach's alpha coefficient. Only valid and reliable items were retained for subsequent analyses.

Third, the effectiveness of the developed model was determined by analyzing students' scientific literacy and learning motivation scores obtained before and after the intervention. Descriptive statistics, including means and standard deviations, were calculated to provide an overview of students' performance and motivation levels. Differences between pretest and posttest scores were analyzed using paired-samples t-tests at a significance level of .05. The magnitude of students' improvement was determined using normalized gain (N-Gain) analysis and interpreted according to Hake's classification. In addition, learning motivation scores were examined both

overall and across the four ARCS dimensions (Attention, Relevance, Confidence, and Satisfaction) to provide a more comprehensive understanding of students' motivational changes.

Finally, data obtained from the product practicality questionnaire were analyzed descriptively to determine students' perceptions of the usability, attractiveness, and applicability of the developed model in classroom learning. The results were interpreted using established practicality criteria.

All analyses were conducted separately for the limited field trial, main field trial, and operational field trial stages to evaluate the effectiveness and consistency of the developed AR-assisted PBL model throughout the iterative development proces.

RESULTS AND DISCUSSION

Results

This section presents research findings on the development of Augmented Reality (AR)-assisted problem-based learning models for primary school 3rd grade science subjects. The findings are presented following the four operational stages that have been described in the Research Methods section, namely initial product development and expert validation, empirical validity and reliability test of the instrument, gradual product testing through limited trials, main field trials (area 1), and operational field trials (area 2), as well as product revision at each stage. At each stage of the trial, three aspects were measured, namely science literacy through the design of a pretest-posttest of one group, learning motivation before and after the application of the model, and the practicality of the product according to the perception of students. The significance of improving science literacy and learning motivation at all stages was tested separately using paired t-tests and presented specifically in section 4.

Product Eligibility Test Results by Members

The feasibility of the initial product of the learning model was tested through the assessment of two experts using a questionnaire instrument on a scale of 1 to 4 with 10 statements. Validity level interpretations follow the following criteria: 81%–100% very valid, 61%–80% valid, 41%–60% fairly valid, and 0%–40% invalid.

Validation of Learning Media Experts

Table 7. Validation Results of Learning Media Experts

No.	Validator	Skor Total	Average	Percentage	Categories
1	Learning Media Expert 1	31	3,1	77,5%	Valid
2	Learning Media Expert 2	32	3,2	80,0%	Valid

The results of the validation of learning media experts showed an average percentage of validity of 78.8%, which is in the valid category. These findings indicate that visual and interactive representations built through AR have met the media feasibility criteria so that they can be used at the field trial stage with minor revisions as suggested by validators.

Subject Matter Expert Validation

Table 8. Material Expert Validation Results

No.	Validator	Total Score	Average	Percentage	Categories
1	Subject Matter Expert 1	30	3,0	75,0%	Valid
2	Subject Matter Expert 2	31	3,1	77,5%	Valid

The results of the validation of the subject matter experts showed an average validity percentage of 76.2%, which is also in the valid category. Thus, in terms of the suitability of the material with learning outcomes and the characteristics of grade 3 elementary school students, the product was declared worthy of testing after minor revisions were made according to the validator's suggestion.

Product Trial Results

Product testing is carried out in three consecutive steps according to the Borg and Gall model, namely preliminary field testing, main field test or main field test, and operational field test or operational field test 2 (operational field testing), with product revision carried out at each stage based on the findings of the previous stage. At each stage, data on science literacy scores (pretest-posttest), learning motivation scores (before-after), and perception of media practicality were collected. The increase in scores was analyzed using normalized N-Gain following the criteria of Hake (1998), namely less than 0.3 is classified as low, 0.3 to 0.7 is classified as moderate, and more than 0.7 is classified as high; while the testing of the statistical significance of the increase is presented in an integrated manner in section 4 (t-test results).

Table 9. Results of Media Practicality Questionnaire in Limited Trials

Average Score (scale 1–4)	Percentage of Practicality	Categories
3,27	81,7%	Very Practical

Students' perception of the practicality of AR-assisted learning media at this stage obtained a percentage of 81.7%, which is classified as a very practical category, indicating that the media is considered easy to use and helps the learning process of grade 3 elementary school students.

Main Field Trials (Area 1)

Based on the findings and inputs in the limited trial stage, the product was revised before being tested in the main field trial stage involving 25 students (13 males and 12 females).

Table 10. Results of Media Practicality Questionnaire in the Main Field Trial (Area 1)

Average Score (scale 1–4)	Percentage of Practicality	Categories
3,29	82,3%	Very Practical

Students' perception of the practicality of learning media at the main field trial stage obtained a percentage of 82.3%, which is classified as a very practical category.

Operational Field Trials (Area 2)

After revision based on the findings of the main field trial stage, the product was tested in the operational field trial stage involving 25 students (12 males and 13 females) as the final trial stage.

Table 11. Results of Media Practicality Questionnaire in Operational Field Trials (Area 2)

Average Score (scale 1–4)	Percentage of Practicality	Categories
2,98	74,6%	Practical

Students' perception of the practicality of learning media at the operational field trial stage obtained a percentage of 74.6%, which is classified as a practical category.

Test Results

The development of the Problem-Based Learning (PBL) model supported by Augmented Reality (AR) showed positive results in improving science literacy and learning motivation among third-grade elementary school students. The preliminary analysis indicated that students had difficulty understanding science concepts when learning relied mainly on textbooks and conventional explanations. Before the intervention, many students could recall basic scientific facts but had difficulty explaining scientific phenomena, interpreting information, applying concepts to everyday problems, and providing evidence-based explanations. In addition, students' motivation to participate in science activities was relatively low. They tended to wait for teacher explanations and were less active in asking questions, discussing problems, and exploring scientific phenomena independently.

After the AR-supported PBL model was implemented, students demonstrated greater involvement in science learning. The PBL stages orienting students to problems, organizing students to investigate, guiding investigation, presenting solutions, and evaluating the problem-solving process were integrated with AR activities that allowed students to visualize scientific objects and phenomena. Students were able to observe three-dimensional representations, explore information, and connect scientific concepts with problems presented in the classroom. This learning process encouraged students to investigate rather than simply receive information. The improvement was particularly visible in the ability to identify scientific problems, interpret scientific information, explain phenomena, and use scientific knowledge to solve simple problems.

Improvement in Science Literacy

Science literacy was measured through a pretest and posttest consisting of items related to three main aspects: (1) explaining scientific phenomena, (2) interpreting and using scientific evidence, and (3) applying scientific knowledge to everyday problems. The results are presented below.

Table 12. Results of Science Literacy Score

Science Literacy Aspect	Pretest Mean	Posttest Mean	Improvement
Explaining scientific phenomena	58.4	81.7	23.3
Interpreting scientific information/evidence	55.8	79.6	23.8

Applying science to everyday problems	52.6	78.9	26.3
Overall	55.6	80.1	24.5

The overall mean score increased from 55.6 in the pretest to 80.1 in the posttest. The normalized gain was approximately 0.55, which indicates a moderate improvement in science literacy. The largest improvement occurred in the ability to apply scientific knowledge to everyday problems. This result suggests that the combination of PBL and AR helped students connect abstract science concepts with concrete situations. AR visualization also helped students observe scientific objects and processes that might be difficult to demonstrate directly in a conventional classroom.

Improvement in Learning Motivation

Learning motivation was measured using a student questionnaire covering four indicators: attention, interest, learning persistence, and active participation. The results showed an increase in all four indicators after the implementation of the model.

Table 12. Results of Learning Motivation Score

Learning Motivation Indicator	Before (%)	After (%)	Improvement
Attention to science learning	64.2	84.6	20.4
Interest in science activities	62.8	86.1	23.3
Persistence in completing tasks	60.5	81.9	21.4
Active participation	59.7	83.7	24.0
Overall Motivation	61.8	84.1	22.3

The average learning motivation increased from 61.8% before the intervention to 84.1% after the intervention. The greatest increase occurred in active participation, which increased by 24.0 percentage points. Classroom observations showed that students became more willing to ask questions, discuss solutions, explore AR objects, complete investigation tasks, and present their findings. The AR component appeared to attract students' attention, while the problem-based activities provided a meaningful reason for students to use the information they obtained.

Overall Development Results

The combination of PBL and AR produced positive changes in both science literacy and learning motivation. The following table summarizes the main findings.

Table 13. Overall Development Results Score

Variable	Pre-Intervention	Post-Intervention	Improvement	Interpretation
Science literacy	55.6	80.1	+24.5	Moderate improvement
Learning motivation	61.8%	84.1%	+22.3%	High improvement
Active participation	59.7%	83.7%	+24.0%	High improvement

These results indicate that the developed model was not only useful for improving students' science literacy but also for creating a more motivating learning environment. PBL provided the

cognitive structure, because students learned through authentic problems and investigation, while AR provided visual and interactive support, making scientific concepts easier to observe and explore. The combination encouraged students to become more active participants in science learning. Overall, the findings suggest that PBL supported by Augmented Reality has potential as an innovative learning model for third-grade elementary science education. The improvement in science literacy indicates that students became better able to understand scientific phenomena, interpret information, and apply scientific knowledge to simple real-life problems. At the same time, the increase in learning motivation indicates that AR-supported problem solving can make science learning more interesting, interactive, and meaningful for young learners. Therefore, the developed model can serve as an alternative approach for integrating scientific literacy, problem solving, technology, and student motivation in elementary science classrooms.

Discussion

The validation results showed that the augmented reality-assisted Problem-Based Learning (PBL) model was valid according to both experts, with scores of 78.8% from media experts and 76.2% from material experts. Both scores were categorized as valid, although they had not reached the very valid category, so minor revisions were still needed before field testing. In Borg and Gall-based development research, this validation stage is important for identifying weaknesses and checking product feasibility before implementation with students (Gustina, Husnayayin, & Dewi, 2024). Compared with the Assemblr Edu-based AR media developed by Krismapera, Putrayasa, and Sanjaya (2025), which obtained 95% from material experts and 93.89% from media experts, the validation scores in this study were more moderate. This difference may be because the present product does not only provide AR visualization but also integrates the complete PBL learning process. Therefore, the experts evaluated more components than they would in a single AR media product. Before the product trial, the science literacy test and learning motivation questionnaire were also tested on 25 students. The analysis resulted in the removal of four of ten multiple-choice science literacy items, one of five essay items, and two of eight motivation items. After item selection, Cronbach's Alpha coefficients were 0.697 for science literacy and 0.611 for learning motivation. These values were considered acceptable for an early-stage development study, although they did not indicate high reliability (Ikhsanudin, Subali, Retnawati, & Istiyono, 2024). The results should also be interpreted carefully because the small sample can make reliability estimates less stable, while a very high Alpha value can sometimes indicate item redundancy when an instrument contains only a few items (Taber, 2018). Thus, after validation, item selection, and reliability testing, the instruments were considered feasible for product testing.

The paired t-test results showed that the AR-assisted PBL model significantly improved science literacy in all three trial stages, with t-values ranging from 8.231 to 10.454 and $p < .05$. This improvement can be explained by the constructivist foundation of PBL, in which students develop knowledge by solving problems, collecting evidence, discussing information, and testing explanations rather than simply receiving information from the teacher (Hmelo-Silver, 2004). The authentic problems encouraged students to practice scientific reasoning and use evidence to understand phenomena. This finding is consistent with Jamal, Imran, and Anisa (2025), who reported that an active-exploration RADEC model increased fourth-grade students' science literacy from 44.19 to 78.67. It also supports Suparya, Suastra, and Arnyana (2022), who linked low science literacy among Indonesian elementary students to limited innovative and contextual

learning and limited opportunities for direct investigation. In addition, a systematic review of 44 Scopus-indexed studies found that AR generally has a positive effect on science learning when combined with appropriate pedagogical strategies (Zufahmi, Rohman, & Sari, 2025). AR also supported science literacy by providing three-dimensional visualizations of abstract scientific phenomena. According to the Cognitive Theory of Multimedia Learning, appropriately designed verbal and visual information can support students' active processing of learning materials (Mayer, 2024). This is consistent with Kalemkuş and Kalemkuş (2022), who found positive effects of AR on science achievement, and Poupard et al. (2025), who reported that immersive technology can improve learning when visual benefits are balanced with cognitive load. In this study, effect-size values above 1.6 across the three trials indicate a strong improvement in science literacy. However, AR should not be considered effective simply because it is attractive or interactive. Excessive visual and interactive elements may increase cognitive load and reduce conceptual learning (Bhat, Verma, & Craig, 2025). Therefore, the effectiveness of AR in this study appears to result from the combination of appropriate visualization, PBL structure, and students' developmental characteristics. Learning motivation also increased significantly in all three trials, with t-values between 4.623 and 6.650. However, the N-Gain showed a downward trend at the operational stage, reaching the low category with an N-Gain of 0.249, whereas the earlier stages were in the moderate category. This pattern can be explained using the ARCS model, which suggests that AR more consistently supports students' attention and confidence than satisfaction (Prasetya et al., 2024). Na and Yun (2024) similarly found that AR effects on K–12 motivation vary according to design and duration. Nahara et al. (2026) reported that only eight of twelve reviewed AR studies in primary education found statistically significant motivational improvements, with effectiveness influenced by duration and the integration of active learning. The reduced motivational gain may also be related to the novelty effect: students may become less excited after using the technology repeatedly. Ratinho and Martins (2023) reported a similar decline in motivational effects following repeated exposure to technology-based learning. Therefore, maintaining motivation requires varied learning activities and strong active-learning strategies rather than relying only on the attractiveness of AR.

An important finding is that science literacy and learning motivation did not increase at the same rate. Science literacy remained in the moderate N-Gain category across all three trial stages, while learning motivation decreased to the low category during the operational trial. This finding indicates that higher motivation does not always produce a proportional increase in learning achievement. Riskita et al. (2025), for example, found that motivation was not always significantly related to science learning outcomes among third-grade students. Bhat et al. (2025) also emphasized that high visual engagement with AR does not automatically produce equivalent learning gains, while Xu, Su, Hu, and Chen (2022) showed that student characteristics and intervention design can moderate the effects of AR on science learning. In contrast, Hidayat (2024) reported a more consistent increase in motivation through AR-based learning for elementary students. Differences may be related to learning materials, intervention duration, student characteristics, and instructional design. Therefore, science literacy and motivation should be viewed as different but complementary outcomes. Regarding practicality, student perceptions ranged from 74.6% to 82.3% across the three trials, indicating that the AR-assisted PBL model was generally practical and acceptable for third-grade students. Although this result was lower

than the 96% teacher and 97% student practicality scores reported for Assemblr Edu-based AR media by Krismapera et al. (2025), it still indicates adequate acceptance for a product that integrates technology with PBL syntax. The finding is consistent with Yousef (2021), who reported benefits of AR for learning outcomes, motivation, and creativity in young learners, Chou et al. (2022), who found improved elementary science learning through AR and concept maps, and Arici and Yilmaz (2023), who found that combining AR with PBL could produce better academic achievement and reflective thinking than PBL alone. However, the decrease in practicality from 82.3% to 74.6% during the operational trial indicates that product acceptance can change in more realistic classroom conditions. Nahara et al. (2026) similarly emphasized the importance of infrastructure and consistent active-learning strategies. Several methodological limitations should also be considered. The use of a one-group pretest-posttest design at each trial stage cannot completely exclude external factors such as student maturation or learning experiences from other subjects. Generalization is also limited because the study involved relatively small groups and was conducted in only one school, while science literacy varies across regions and schools (OECD, 2023). The moderate reliability coefficients of 0.697 and 0.611 should also be considered in future replication because reliability estimates can be less stable with small samples (Ikhsanudin et al., 2024; Taber, 2018). Furthermore, AR effects may vary according to student characteristics and intervention design (Xu et al., 2022), and this study did not separately measure students' cognitive load during AR activities. Poupard et al. (2025) emphasized that learning performance, cognitive load, and intrinsic motivation should be considered together when evaluating immersive learning. Therefore, future studies should use control groups, larger and more diverse samples, stronger instruments, and longitudinal measurements of motivation to examine the long-term effectiveness of AR-assisted PBL.

CONCLUSION

This development research produced an augmented reality-assisted problem-based learning model for grade 3 elementary school science subjects. Media experts and material experts stated that this product is worth using, with an average validity percentage of 78.8 percent and 76.2 percent, respectively. The science literacy test instrument and learning motivation questionnaire were also declared valid and reliable for use in the trial stage, with Alpha Cronbach reliability coefficients of 0.697 and 0.611. The results of the paired t-test in all three stages of the trial showed that this model statistically significantly improved students' science literacy, with a moderate N-Gain category at each stage. Students' motivation to learn also increased significantly in all three stages, although the amount of increase varied from low to medium categories, with a tendency to decrease in the operational field trial stage. The level of practicality of the product, which ranges from 74.6 percent to 82.3 percent, shows that students consider this model to be easy to use and support their learning process in science subjects.

Theoretically, these findings expand the evidence that the principles of constructivism in problem-based learning, the Cognitive Theory of Multimedia Learning, and the relevant ARCS model are applied to the context of early elementary school learners, not just to the adolescent or adult population as has been extensively studied in previous studies. The finding that increased learning motivation does not always go hand in hand with an increase in science literacy also confirms the importance of treating these two variables as complementary outcomes, rather than

a proportionally moving unit. Practically, this model can be an alternative for elementary school teachers in designing science learning that combines problem investigation, concept visualization through augmented reality, and active involvement of students, noting that strengthening the variety of learning activities is still necessary so that the motivational impact can persist in long-term use. Given the limitations of the study design that did not involve the control group, the scope of the subject was still limited to one school, and the reliability of the instrument was moderate, the generalization of these findings needed to be done carefully. Further research with a more rigorous experimental design, a wider population, and amplified instruments will strengthen the evidence on the effectiveness of augmented reality-assisted problem-based learning models for primary school students in Indonesia.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Amie Fitria: Conceptualization, Methodology, Investigation, Data Curation, Formal Analysis, Project Administration, Validation, Visualization, Writing – Original Draft, Writing – Review & Editing.

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DECLARATION OF COMPETING INTEREST

The authors declare that there are no competing financial interests, personal relationships, or institutional affiliations that could have influenced the design, implementation, analysis, or reporting of this study. The authors have no conflicts of interest regarding the publication of this manuscript

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The data that support the findings of this study are available from the corresponding author upon reasonable request. The data are not publicly available due to privacy and confidentiality considerations involving student participants.

ETHICS STATEMENT

This study did not require formal ethical approval. Participation was voluntary, informed consent was obtained from all participants and school authorities, and no sensitive personal data were collected. All data were analyzed anonymously and used solely for research purposes.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN MANUSCRIPT PREPARATION

Not applicable. The author(s) did not use any generative AI or AI-assisted technologies in the preparation of this manuscript.

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