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Development of Augmented Reality (AR) Instructional Media Based on Problem-Based Learning (PBL) for the Solar System Topic for Ninth-Grade Students at SMP Negeri 2 in Ternate City

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A B S T R A C T
This study aims to describe the development stages of a Problem-Based Learning (PBL)-based Augmented Reality (AR) learning media on the topic of the Solar System, as well as to evaluate its feasibility, practicality, and effectiveness in improving concept understanding and critical thinking skills among 9th-grade students at SMP Negeri 2 Kota Ternate. The research employed a Research and Development (R&D) method using Lee & Owens' procedural model. The results indicated high expert validation scores: material expert at 95.59% (highly valid), media expert at 96.32% (highly valid), and learning practitioner at 98.33% (highly valid). The practicality test via student response questionnaires yielded 97% (highly practical). Furthermore, the effectiveness test revealed a highly significant difference in post-test results between the experimental and control groups ($F = 21.922$, $Siq < 0.001$). The average cognitive gain in the experimental group reached 33.44 points, increasing from 55.13% to 88.57%. Based on these findings, the PBL-based AR learning media is declared highly feasible, practical, and effective in enhancing students' critical thinking skills and concept understanding in learning the Solar System.

INTRODUCTION

The development of information and communication technology in the 21st century has brought significant impacts to the education sector, especially in the school learning process. Modern education is demanded not only to be oriented towards factual knowledge mastery but also towards the development of higher-order thinking skills such as critical thinking, problem-solving, creativity, and deep conceptual understanding. The Independent Curriculum (Kurikulum Merdeka) and national education policies emphasize the importance of student-centered learning and the use of technology as a means to improve learning quality (Kemendikbudristek, 2022). However, the implementation of technology-based learning and the development of critical thinking skills in junior high schools still face various obstacles, particularly in science subjects.

Natural Sciences (Ilmu Pengetahuan Alam / IPA) is a subject that plays a strategic role in forming logical, critical, and systematic thinking skills for students. One science topic considered complex and abstract for junior high school students is the Solar System. This topic requires high visualization skills because study objects such as planets, rotation, revolution, and celestial motion cannot be observed directly by students. Research conducted by Sari and Handayani (2020) in the Jurnal Pendidikan IPA Indonesia indicates that most students experience misconceptions regarding the Solar System due to the limitations of learning media used by teachers, which are generally still in the form of textbooks and two-dimensional images.

Facts in the field show that science learning at the junior high school level, especially on the Solar System topic, is still dominated by lecture methods and two-dimensional (2D) media. This condition impacts students' low conceptual understanding and underdeveloped critical thinking skills. Research findings by Rahmawati et al. (2021) in the Jurnal Inovasi Pendidikan IPA reveal that students tend to memorize concepts without understanding the interrelations between concepts, thus struggling with problem-based questions. This phenomenon was also found at SMP Negeri 2 Ternate City, where learning evaluation results showed that most 9th-grade students had not achieved learning mastery on the Solar System topic.

The ideal expectation of the science learning process is the creation of meaningful, contextual learning capable of developing students' critical thinking skills. Learning should provide direct learning experiences through exploration, observation, and problem-solving relevant to daily life. According to Prasetyo and Widodo (2019), effective learning is one that is able to integrate innovative learning models with media matching the characteristics of the material and students, so that students not only understand concepts theoretically but are also able to apply these concepts in various situations. However, a gap often exists between expectations and reality in the implementation of science learning in schools. This gap lies in the limited use of interactive and innovative learning media and the suboptimal implementation of learning models emphasizing problem-solving. Teachers still face obstacles in developing technology-based media due to limited knowledge and time, causing learning to remain teacher-

centered and providing insufficient room for students to think critically (Utami & Lestari, 2020).

One effort to bridge this gap is by developing Augmented Reality (AR)-based learning media. AR is a technology capable of combining three-dimensional virtual objects with the real environment in real-time, providing a more concrete and interactive learning experience. Research by Kurniawan et al. (2021) in the Jurnal Teknologi Pendidikan shows that using AR media in science learning can significantly improve students' conceptual understanding because students can view object visualizations that were previously abstract. The use of AR media becomes even more relevant when combined with the Problem-Based Learning (PBL) model. PBL is a learning model emphasizing the presentation of real-world problems as a starting point for learning, thereby encouraging students to think critically, collaborate, and seek solutions independently. According to research findings by Wulandari and Suyanto (2022) in the Jurnal Pendidikan Sains Indonesia, the application of PBL is proven effective in improving critical thinking skills and problem-solving abilities of junior high school students in science subjects.

The integration of AR-based learning media with the PBL model is expected to create more meaningful and contextual learning, especially on the Solar System topic. AR media can help students visualize abstract concepts, while PBL provides a challenging learning framework prompting students to analyze problems, formulate hypotheses, and draw conclusions. Research by Nurhayati et al. (2023) shows that the combination of interactive media and the PBL model positively impacts the improvement of students' critical thinking skills and conceptual understanding.

The main reason for selecting the development of PBL-based Augmented Reality learning media in this study is that this approach matches the characteristics of the Solar System topic and the needs of junior high school students. Students at this stage are at the early formal operational cognitive development stage, thus requiring visual assistance and concrete learning experiences to understand abstract concepts (Putra & Rahayu, 2020). Furthermore, the use of AR technology aligns with the characteristics of the digital generation familiar with technology devices such smartphones. Based on this elaboration, the researcher conducted a study titled "Development of Augmented Reality (AR) Learning Media Based on Problem-Based Learning (PBL) to Improve Concept Understanding and Critical Thinking on Solar System Topics for 9th-Grade Students at SMP Negeri 2 Ternate City." This study is expected to provide a real contribution to the development of science learning innovations at SMP Negeri 2 Ternate City and serve as a reference for teachers in effectively implementing technology- and problem-solving-based learning.

THEORETICAL REVIEW

Nature of Learning Media

Learning media are instruments or vehicles facilitating message delivery, stimulating cognition, affection, and student learning motivation to create an effective and conducive learning atmosphere (Arsyad, 2020).

Concept and Characteristics of Augmented Reality (AR)

Augmented Reality (AR) is an interactive technology projecting two- or three-dimensional digital objects into the real environment in real-time (Azuma, 1997). AR allows users to continue interacting with their surrounding physical environment while acquiring additional visual information based on digital objects (Wu et al., 2021).

The Role of AR in Science Learning

The use of AR in science education facilitates students in visualizing abstract materials or macrocosms that cannot be observed directly in the classroom. Interactive 3D visualization based on AR helps reduce cognitive load and enhances students' spatial understanding of abstract concepts (Ibáñez & Delgado-Kloos, 2022).

Nature of Problem-Based Learning

Problem-Based Learning (PBL) is a constructivist-oriented learning model placing real-world problems (authentic/contextual problems) as a trigger for students to identify knowledge, investigate solutions, and integrate science concept understanding (Arends, 2012).

Integration of AR in PBL Syntax

The integration of AR media within PBL syntax functions as a digital scaffolding instrument during the inquiry guidance stage. Students use AR 3D objects to collect visual data, test hypotheses, and solve scientific problems collaboratively (Nincarean et al., 2022; Utami et al., 2023).

METHODOLOGY

This type of research is research and development (R&D). The development model used in this research is the Lee and Owens model, which consists of five stages: 1) Analysis, divided into needs analysis and front-end analysis, 2) Design, 3) Development, 4) Implementation, and 5) Evaluation. This model is a procedural model describing steps that must be followed gradually from the initial step to the final step to produce a feasible product.

The trial design used to test product effectiveness is the Pretest-Posttest Non-equivalent Control Group Design. In this design, the research involves two groups: the experimental class and the control class. The subjects of this study were 9th-grade students at SMP Negeri 2 Ternate City. The sample consisted of two classes: one class as the experimental group (using PBL-based AR media, n=30) and one class as the control group (using conventional media/textbook based on PBL, n=30).

Instruments used by the researcher for data collection in this study include observation, interviews, validation questionnaires by material experts, media experts, learning practitioners, student response practicality questionnaires, and cognitive written test instruments (pretest and posttest) consisting of 15 multiple-choice items. Data analysis techniques are divided into two: descriptive analysis for product feasibility percentages and inferential analysis using Analysis of

Covariance (ANCOVA) aided by SPSS to test product effectiveness by controlling students' initial ability (pretest).

RESULTS

Development Stages of Problem-Based Learning (PBL)-Based Augmented Reality (AR) Learning Media on Solar System Topics to Improve Critical Thinking and Concept Understanding of 9th-Grade Students at SMP Negeri 2 Ternate City

The development stage resulted in an Android-based interactive application named *Unity AR Tata Surya* featuring main menus: Scan AR, Mini Quiz, User Guide, and Exit. The Scan AR menu presents planet identity cards as markers to display dynamic 3D objects that students can explore spatially, validated by experts and learning practitioners as seen in Table 1 below.

Table 1. Expert and Learning Practitioner Validation Results

No	Validator Group	Score Percentage	Criteria
1	Science Material Expert	95.59%	Highly Valid
2	Media Design Expert	96.32%	Highly Valid
3	School Science Practitioner Teacher	98.33%	Highly Valid

Based on Table 1, the table above presents the feasibility assessment (validation) results of the Problem-Based Learning (PBL)-based Augmented Reality (AR) learning media conducted by three groups of experts/specialists. Based on these data, it can be stated that:

1. **Science Material Expert:** Assessment from the material expert obtained a score percentage of 95.59% with the Highly Valid criteria. This indicates that the Solar System material presented in the AR media matches the curriculum, is scientifically accurate, and aligns with indicators of students' conceptual understanding and critical thinking.
2. **Media Design Expert:** Assessment from the media expert obtained a score percentage of 96.32% with the Highly Valid criteria. This result proves that aspects of 3D visual clarity, navigation ease, AR feature interaction quality, and user interface design of the developed learning media meet excellent educational media quality standards.
3. **School Science Practitioner Teacher:** Assessment from practitioners (science teachers) obtained the highest score percentage of 98.33% with the Highly Valid criteria. This score indicates that the learning media is highly applicable, relevant to the learning needs of 9th-grade junior high school students, and easily implemented by teachers within problem-based learning (PBL) syntax.

Overall, this Problem-Based Learning (PBL)-based Augmented Reality (AR) learning media on the Solar System topic is declared Highly Valid from material, media, and learning practicality aspects, making it highly feasible to proceed to field testing.

Feasibility, Practicality, and Effectiveness of Problem-Based Learning (PBL)-Based Augmented Reality (AR) Learning Media on Solar System Topics to Improve Critical Thinking and Concept Understanding of 9th-Grade Students at SMP Negeri 2 Ternate City

Based on the developmental research conducted in 9th-grade at SMP Negeri 2 Ternate City, the feasibility, practicality, and effectiveness levels of the PBL-based AR learning media on the Solar System topic are described through Figure 1.

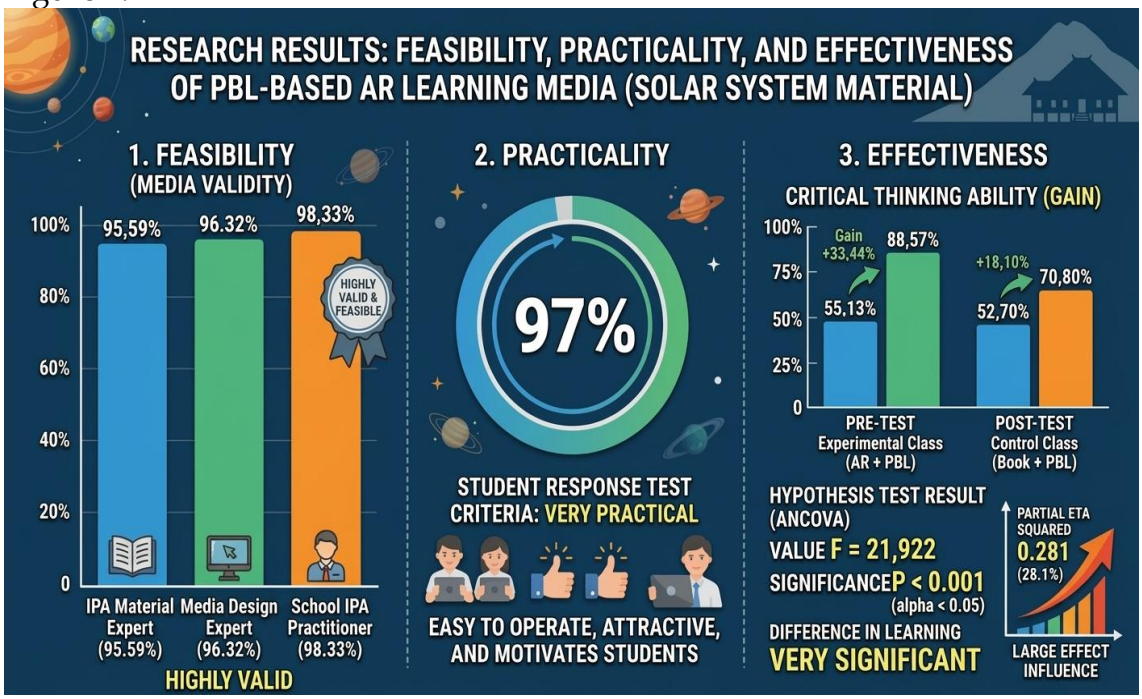


Figure 1 . Feasibility, Practicality, and Effectiveness of Problem-Based Learning (PBL)-Based Augmented Reality (AR) Learning Media on Solar System Topics to Improve Critical Thinking and Concept Understanding of 9th-Grade Students at SMP Negeri 2 Ternate City

Based on Figure 1, the developed learning media is proven Highly Valid and feasible to use based on expert and practitioner assessments: Science Material Experts scored 95.59% (Highly Valid), Media Design Experts scored 96.32% (Highly Valid), and Science Practitioner Teachers scored the highest at 98.33% (Highly Valid), proving that the media is highly applicable and suits school learning needs. Furthermore, based on media practicality tests through student response questionnaires, 97% was obtained with the Highly Practical criteria. Then, effectiveness showed that critical thinking ability (Gain) and student concept understanding for the Experimental class (AR+PBL) showed an average increase (gain) of +33.44% (from a pre-test of 55.13% to a post-test of 88.57%). Meanwhile, the Control class (Book + PBL) showed an increase of +18.10% (from a pre-test of 52.70% to a post-test of 70.80%). Furthermore, Hypothesis Testing results (ANCOVA) yielded statistical test results of $F = 21.922$ with a significance value of $p < 0.001$ ($\alpha < 0.05$). This proves a very significant difference in learning outcomes between the experimental and control classes. A Partial Eta Squared value of 0.281 (28.1%) indicates that the use

of PBL-based AR media provides a large effect size on improving students' critical thinking and cognitive skills.

Table 2. Students' Average Critical Thinking Skills

Class Group	Total (n)	Pre-Test Average	Post-Test Average	Increase (Gain)
Experiment (AR + PBL)	30	55.13%	88.57%	+ 33.44%
Control (Book + PBL)	30	52.70%	70.80%	+ 18.10%

Table 2 presents comparative data on students' critical thinking skills between the Experimental Class (using Problem-Based Learning-based Augmented Reality media) and the Control Class (using Problem-Based Learning-based Textbooks), with 30 students each ($n = 30$). Based on these data, several main points can be described as follows:

4. **Students' Initial Condition (Pre-Test):** Before treatment was given, students' average critical thinking skills in both groups were at a relatively equal and moderate/low category level, namely 55.13% for the experimental class and 52.70% for the control class. This initial condition equality indicates that both groups started from a balanced initial understanding and critical reasoning point before media intervention.
5. **Students' Final Achievement (Post-Test):** After the learning process implementation, an increase in critical thinking skills occurred in both classes. However, the Experimental Class achieved a much higher post-test average of 88.57% (Very Good/High category), while the Control Class only reached 70.80% (Good/Moderate category).
6. **Increase in Critical Thinking Skills (Gain):** The Experimental Class experienced an average gain increase of +33.44% (from 55.13% to 88.57%). The Control Class experienced an average gain increase of +18.10% (from 52.70% to 70.80%). There is a significant difference in increase of 15.34% higher in the experimental class compared to the control class. The experimental class's critical thinking increase of 33.44% far outperforms the control class (18.10%). After normality and variance homogeneity prerequisites were met, analysis continued with inferential ANCOVA tests.

Table 3. SPSS ANCOVA Hypothesis Test Results Output

Source of Variance	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Group	79.995	1	79.995	21.922	< 0.001	0.281
Error	204.351	56	3.649			

Based on the ANCOVA test results in Table 3, an F value of 21.922 was obtained with a significance value of < 0.001 on the group variable. This

significance value is smaller than 0.05, indicating that there is a significant post-test result difference between the experimental group and the control group after controlling for the effect of pre-test scores. Thus, H_0 is rejected and H_a is accepted. A Partial Eta Squared value of 0.281 indicates that the contribution of using PBL-based AR media provides a strong influence of 28.1% on student cognitive learning outcomes.

The synergy between AR 3D object visualization and Problem-Based Learning (PBL) syntax provides a strong link between Solar System material abstraction and students' critical thinking activities. Students are guided to actively observe phenomena, collect investigation data interactively via smartphones, engage in group discussions, and formulate contextual problem-solving solutions in depth.

DISCUSSION

Science material expert validator validators gave a score of 95.59%, media design expert validators gave a score of 96.32%, and learning practitioners (school science teachers) gave the highest score of 98.33%, all three falling under the "Highly Valid" criteria. This exceptionally high validation score achievement indicates that the developed learning media product has met substantial and technical quality standards before field testing. Assessments from material experts prove that science scientific substance, Solar System concept coverage, and astronomical fact accuracy presented in the media align with the curriculum and student competency needs (Kusuma et al., 2022). Meanwhile, validation scores from media experts confirm that software engineering aspects, three-dimensional visual displays, user interface layouts, and application navigation ease have been designed ergonomically and interactively to support digital learning processes (Wu et al., 2021). Teacher involvement in the validation process ensures that the Problem-Based Learning (PBL) syntax integrated into the media accommodates contextual problems in the classroom well (Utami et al., 2023). Thus, based on comprehensive validation from experts and practitioners, the PBL-based AR learning media is declared theoretically and practically very feasible to implement in learning activities to improve students' conceptual understanding and critical thinking skills (Nincarean et al., 2022; Pratama et al., 2023).

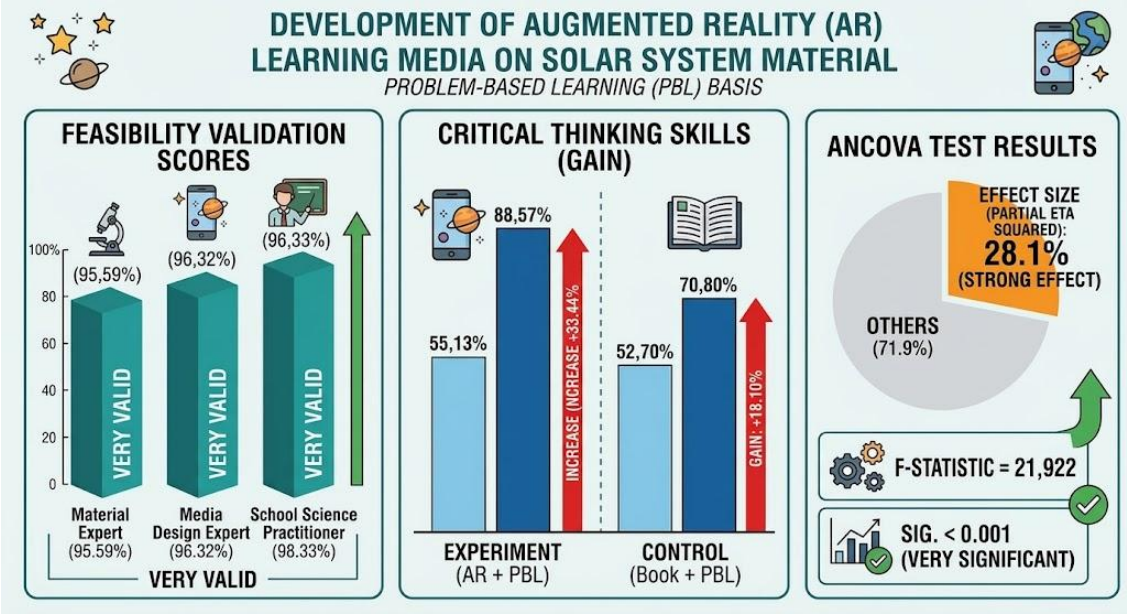


Figure 2. Graph of validation scores, critical thinking skills, and ANCOVA test results

Based on the data in Table 2, descriptive analysis results show that before treatment (pre-test), students' initial critical thinking skills in the experimental and control groups were at relatively equal and low categories, namely 55.13% and 52.70% respectively. This initial score equality indicates that both sample groups possessed balanced initial cognitive abilities and critical reasoning, so changes or increases occurring after treatment are purely the impact of the learning intervention provided. These findings align with research proposed by Kusuma et al. (2022) and Utami et al. (2023), stating that interactive digital visualization utilization is able to facilitate independent knowledge construction and strengthen abstract conceptual understanding. Through the application of the Problem-Based Learning (PBL) model combined with AR media, students are placed as active subjects confronted with contextual problems. PBL syntax requiring students to identify problems, collect data through virtual investigations, and analyze scientific evidence runs optimally supported by realistic AR 3D objects (Nincarean et al., 2022; Pratama et al., 2023). This directly stimulates Ennis's critical thinking indicators, such as the ability to analyze arguments, test hypotheses, and draw conclusions logically based on accurate visual observations (Rahman et al., 2022). Consequently, the use of PBL-based AR media proves far superior in boosting students' critical thinking skills compared to conventional textbook-based learning.

Based on the ANCOVA test results in Table 3, an F value of 21.922 was obtained with a significance value of < 0.001 on the group variable. This significance value is much smaller than the 0.05 significance level, indicating a very significant post-test result difference between the experimental and control groups after controlling for pre-test score effects. This finding aligns with studies conducted by Utami et al. (2023) and Pratama et al. (2023), stating that integrating interactive digital technology in problem-based learning significantly boosts academic performance and high-order reasoning compared to conventional

methods. The significant advantage in the experimental class is inseparable from the synergy between AR 3D object visualization and Problem-Based Learning (PBL) syntax providing a strong link between Solar System material abstraction and students' critical thinking activities. Through AR media, spatial barriers are bridged as students are directed to actively observe astronomical phenomena, collect investigation data interactively via smartphones, engage in group discussions, and formulate contextual problem-solving solutions in depth (Nincarean et al., 2022).

Within the PBL syntax framework, AR media functions as a digital scaffolding instrument during the investigation stage. When students face contextual problems regarding celestial body dynamics, rotation, revolution, and planetary characteristics, AR 3D visualization helps reduce cognitive load and helps students build accurate mental representations (Ibáñez & Delgado-Kloos, 2022; Wu et al., 2021). This directly stimulates Ennis's critical thinking indicators, particularly in aspects of analyzing arguments, testing hypotheses, and drawing conclusions based on virtual empirical evidence they observe themselves (Rahman et al., 2022). Thus, utilizing PBL-based AR media proves effective as an innovative solution to improve the quality of science learning processes and outcomes at the junior high school level.

CONCLUSIONS AND RECOMMENDATIONS

This R&D research successfully produced the Android-based 'Unity AR Tata Surya' learning media using the Lee & Owens model. The media was declared highly feasible by material experts (95.59%), media experts (96.32%), learning practitioners (98.33%), and highly practical (97%) based on student responses. Based on ANCOVA tests, the PBL-based AR learning media proved significantly effective (Sig.} < 0.001) in improving critical thinking skills and conceptual understanding of 9th-grade students at SMP Negeri 2 Ternate City on Solar System topics. The Problem-Based Learning (PBL)-based Augmented Reality (AR) learning media on the Solar System is declared highly feasible, highly practical, and highly effective in bridging Solar System material abstraction and improving 9th-grade students' critical thinking skills and concept understanding at SMP Negeri 2 Ternate City.

FURTHER STUDY

This study contributes to utilizing PBL-based AR media in science learning. Nevertheless, further research is urgently needed to expand trial scales to various schools with diverse technology infrastructure readiness levels, develop markerless-based AR media accessible across multi-platforms (cross-device compatibility), and investigate the media's influence on other 21st-century variables, such as student collaboration and creativity.

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