AUGMENTED REALITY DRIVEN STEAM-PJBL : TRANSFORMING CRITICAL THINKING OF SCIENCE EDUCATION

ARTIKEL

Diajukan untuk memenuhi persyaratan tugas akhir pada program studi pendidikan guru sekolah dasar Fakultas Keguruan dan Ilmu Pendidikan Universitas Muhammadiyah Makassar

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UNIVERSITAS MUHAMMADIYAH MAKASSAR

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MAJELIS PENDIDIKAN TINGGI PIMPINAN PUSAT MUHAMMADIYAH
UNIVERSITAS MUHAMMADIYAH MAKASSAR
FAKULTAS KEGURUAN DAN ILMU PENDIDIKAN

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"Augmented Reality-Driven STEM-PjBL: Transforming Critical Thinking in Science Education"

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Abstract

Abstract

The integration of Augmented Reality (AR) into education offers a promising avenue for enhancing critical thinking, yet empirical evidence on its effectiveness particularly within structured pedagogical models—remains limited. This study investigates the impact of AR-assisted Project-Based Learning (PjBL) integrated with STEM (Science, Technology, Engineering, and Mathematics) education on eighth-grade students' critical thinking skills in science learning. Addressing the urgent need for innovative teaching strategies that bridge theoretical knowledge and real-world application, this research employs a quantitative experimental design with two groups: an experimental group using AR-based PjBL-STEM and a control group taught through conventional methods. Pre- and post-tests, complemented by structured observations, were used to assess critical thinking development. Results revealed that students in the experimental group exhibited significantly greater gains in critical thinking compared to the control group. The AR-based PjBL-STEM approach fostered deeper engagement with scientific content, improved problem-solving abilities, and enhanced the transfer of concepts to authentic contexts. These findings underscore the novelty of combining AR with PjBL-STEM as an integrated model that not only enriches learning experiences but also addresses persistent challenges in cultivating higher-order thinking skills in science education. This study contributes to the growing body of knowledge on technology-enhanced pedagogy by providing empirical evidence of AR's potential in structured STEM learning environments. It offers practical insights for educators and policymakers seeking scalable, impactful solutions to promote critical thinking. Future research should examine longitudinal effects and broader applications of AR-based PjBL-STEM across diverse educational settings.

Keywords: *Augmented Reality, Critical Thinking, Project-Based Learning, STEM, Science Education.*

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INTRODUCTION

Science education, particularly in the fields of mathematics and natural sciences, plays a crucial role in shaping students' critical thinking skills (Muttaqiin, 2023). In the 21st century, the ability to think critically is essential in facing various challenges and rapid global changes. Critical thinking skills are not only related to problem-solving abilities but also to the capacity to analyze, evaluate, and make decisions based on available information. In the context of science education, the development of these skills is vital as it affects not only learning outcomes but also students' readiness to participate in an increasingly complex and technology-driven society (R et al., 2023).

As technology advances, teaching methods in science have undergone significant transformations. One promising technology is Augmented Reality (AR), which allows direct interaction between the real and virtual worlds, offering a more immersive and interactive learning experience (Putri & Baharun, 2023; Akbar et al., 2025). In addition, the Project-Based Learning (PjBL) approach integrated with STEM (Science, Technology, Engineering, Mathematics) offers more contextual and applicable learning solutions (Aini et al., 2022; Parno et al., 2022). Recent studies show that the use of AR in science learning can enhance the understanding of abstract concepts and help students connect theory with real-world applications (Alizkan et al., 2021; Widiyono et al., 2023). However, despite the great potential of AR and PjBL-STEM, the combined implementation of both in the context of critical thinking instruction remains limited (Lianti et al., 2023). A major challenge in science learning is the lack of effective approaches to developing students' critical thinking skills. Many students still struggle to identify and solve complex scientific problems (Allanta & Puspita, 2021). They often rely solely on procedural understanding without truly grasping the underlying concepts, resulting in lower-quality problem-solving and innovation. This is reflected in international assessments such as PISA, which indicate that Indonesian students' critical thinking skills in science remain relatively low (Hasibuan et al., 2022). Moreover, although students are interested in science learning, they are often hindered by teaching methods that are less interactive and fail to connect the material to real-life contexts (Rianto et al., 2023).

One common solution to address this problem is the application of active learning models such as PjBL. PjBL is known to facilitate the development of critical thinking skills by encouraging students to solve real-world problems, work collaboratively, and produce products that can be applied in daily life (Aini et al., 2022; Lianti et al., 2023). Furthermore, STEM approaches are increasingly being applied to support more holistic and interdisciplinary science learning (Parno et al., 2022; Widiyono et al., 2023). The integration of PjBL-STEM enables students to apply the concepts they learn in broader contexts, which is expected to enhance their critical thinking skills (R et al., 2023).

Existing literature shows that AR has great potential to improve students' critical thinking skills (Akbar et al., 2025; Putri & Baharun, 2023). AR can make difficult scientific concepts more tangible and easier to understand by combining visual and interactive elements that stimulate students' cognitive processes (Alizkan et al., 2021). Previous studies have shown that AR can enhance students' conceptual understanding, engagement in learning, and problem-solving abilities (Muttaqiin, 2023; Aini et al., 2022). AR technology allows students to view and interact with 3D models of objects or phenomena that are difficult to observe directly in the real world, such as biological processes or chemical reactions (Akbar et al., 2025). Thus, AR can overcome the limitations of conventional learning and offer a more engaging and in-depth way to understand scientific concepts.

However, while many studies discuss the potential of AR and PjBL-STEM in science learning, there is still a gap in research on combining the two to improve students' critical thinking skills (Widiyono et al., 2023; Lianti et al., 2023). Most existing research only examines the effects of AR or PjBL separately, while the integration of both in the context of critical thinking learning has rarely been explored (Parno et al., 2022). This highlights a research gap that needs to be addressed to better understand how AR can support the PjBL-STEM model in developing students' critical thinking skills.

The aim of this study is to evaluate the impact of using AR in PjBL-based STEM learning on students' critical thinking skills (R et al., 2023; Aini et al., 2022). This research seeks to examine whether AR can strengthen the PjBL-STEM approach in enhancing students' critical thinking in science learning (Akbar et al., 2025). Focusing on elementary school students, this study also aims to provide new insights into the application of

technology in science education, particularly in the context of learning that prioritizes the development of critical thinking skills.

METHOD

Research Type and Design

This study employs a quantitative descriptive approach within an experimental framework to evaluate the impact of Augmented Reality-based STEM Project-Based Learning (STEM-PjBL) on students' critical thinking in science education. The quantitative descriptive method is applied to process numerical data—both as raw scores and percentages—to generate comprehensive insights (Akbar et al., 2025; Putri & Baharun, 2023; Suardani et al., 2023). The research design adopts a Pre-Test–Post-Test Control Group Design, selected to rigorously measure the effectiveness of AR-integrated learning media. This design ensures that observed changes in students' critical thinking skills can be directly attributed to the use of AR in the STEM-PjBL model, rather than other uncontrolled variables. Both groups were assessed using the same instrument to measure critical thinking skills, and the data obtained were compared to determine the effectiveness of AR in learning, as summarized in Table 1.

Table 1. Pretest-Posttest Control Group Design

Class	Pre-test	Treatment	Post-test
Experimental	O_1	X_1	O_2
Control	O_1	X_2	O_2

The treatment for the experimental group (X_1) involved implementing Augmented Reality-driven STEM Project-Based Learning (STEM-PjBL) through Android-based interactive multimedia. This approach embedded STEM principles by integrating the core subject of science with other relevant disciplines, fostering deeper conceptual understanding and critical thinking skills. In contrast, the control group (X_2) received instruction through conventional teaching methods without the integration of AR-based interactive multimedia. The overall research procedure from preparation through data analysis is illustrated in Figure 1, providing a visual representation of the procedural flow of this study.

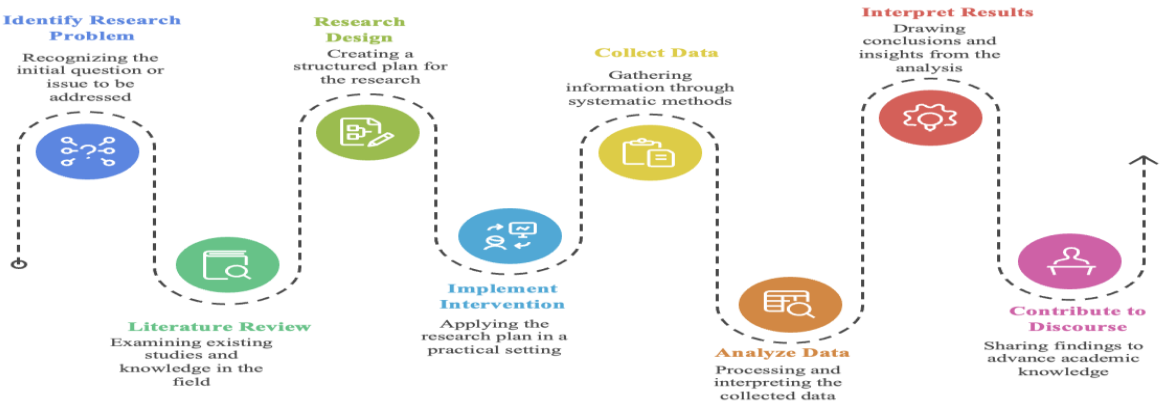

Figure 1. Research Flowchart

The research procedure began by administering a pre-test to both groups to measure students' critical thinking skills prior to the intervention. Following this, the experimental group participated in AR-based learning within the PjBL-STEM framework, while the control group engaged in conventional learning without the use of AR (Muttaqiin, 2023). In the experimental group, the learning process commenced with an introduction to the AR application used in this study, namely *SkyView Lite*. This application was developed to enable students to access science learning materials in a more interactive and immersive format. It provides simulations and visualizations of concepts that are difficult to observe directly, such as the solar system.

Population and Sample

The study was conducted in Grade V at SDN 13 Padang Lampe, Pangkep Regency, with the entire fifth-grade cohort enrolled in the first semester of the 2024/2025 academic year serving as the research population. The sample was selected using cluster random sampling, in which entire classes were randomly chosen rather than individual students. As a result, class Vb (n = 32) was designated as the experimental group, and class Va (n = 33) served as the control group (Widiyono et al., 2023). The separation of experimental and control groups was based on existing class structures, which were then treated according to the designated instructional approach. The experimental group used AR in STEM-PjBL learning, while the control group followed traditional learning without AR. The primary focus of this research was on students' critical thinking abilities, with additional attention given to the quality of STEM-PjBL implementation in science learning.

Data and Research Instruments

The research instruments consisted of a critical thinking skills test and an observation sheet designed to assess the implementation of the learning process, the latter using the Guttman scale. The critical thinking test comprised four essay-type questions on the solar system. Prior to implementation, the test items were validated by experts and subjected to item analysis, which included validity, reliability, difficulty level, and discrimination index testing (Aini et al., 2022; Allanta & Puspita, 2021). The observation sheet was used to evaluate the implementation of STEM-PjBL in the classroom (Parno et al., 2022). The validity and reliability of the instruments were tested before use (Hasibuan et al., 2022). The following is a Critical Thinking Test Instrument: Solar System Topic for Fifth Grade Elementary School Students (Guttman Scale).

Table 2. Critical Thinking Test Instrument: Solar System Topic.

No.	*Question*	*Indicators*	*Assessment Criteria*	*Points (Guttman Scale)*
1	Name the planets in the solar system and explain briefly about each one!	- Name the planets in the solar system. - Mention the characteristics of each planet.	- Mentions all the planets and provides a brief explanation of each. - The explanation is	1: Inadequate 2: Fairly Adequate 3: Adequate 4: Very Adequate

			accurate and easy to understand.	
2	What is gravity? Why is gravity important in the solar system?	- Explains gravity in simple terms. - Mentions the role of gravity in the movement of planets and other celestial bodies.	- A clear explanation of gravity. - Mentions the effects of gravity on planets and celestial bodies.	1: Inadequate 2: Fairly Adequate 3: Adequate 4: Very Adequate
3	Why can Earth support life? What makes it different from other planets in the solar system?	- Mentions the characteristics of Earth that support life (such as temperature, water, and atmosphere). - Compares it with other planets in the solar system.	- Mentions several factors that make Earth suitable for life. - Compares Earth with other planets in a way that's easy to understand.	1: Inadequate 2: Fairly Adequate 3: Adequate 4: Very Adequate
4	What would happen if the Sun suddenly died? Explain how this would affect the solar system!	- Mentions the effects of the Sun's disappearance on the solar system. - Explains the changes that would occur in simple terms.	- Mentions several direct effects of the Sun's disappearance. - Explains it logically and understandably for elementary students.	1: Inadequate 2: Fairly Adequate 3: Adequate 4: Very Adequate

Data Analysis Techniques

The data obtained from the critical thinking tests and observation sheets were analyzed using an Independent Samples t-test to compare differences between the experimental and control groups. This t-test was conducted to determine whether there were significant differences in the improvement of critical thinking skills between the two groups (Lianti et al., 2023; R et al., 2023). In addition, an N-Gain analysis was performed to assess the extent of improvement in each group between the pre-test and post-test. The N-Gain provided an indication of the effectiveness of the learning intervention in enhancing students' critical thinking skills (Aini et al., 2022). Based on the N-Gain results, the improvement categories were classified as low, medium, and high, which were then used to describe the effectiveness of the intervention.

RESULTS AND DISCUSSION

The analysis of the research findings was conducted by comparing the pre-test and post-test scores of the two participating groups: the experimental group and the control group. The experimental group received instruction through a Project-Based Learning model integrated with STEM, supported by Augmented Reality (AR) technology, while the control group followed conventional instruction. This comparison aimed to examine the differences in the improvement of critical thinking skills resulting from the use of the *SkyView Lite* AR application in the context of science learning. Below is a screenshot of the application used.

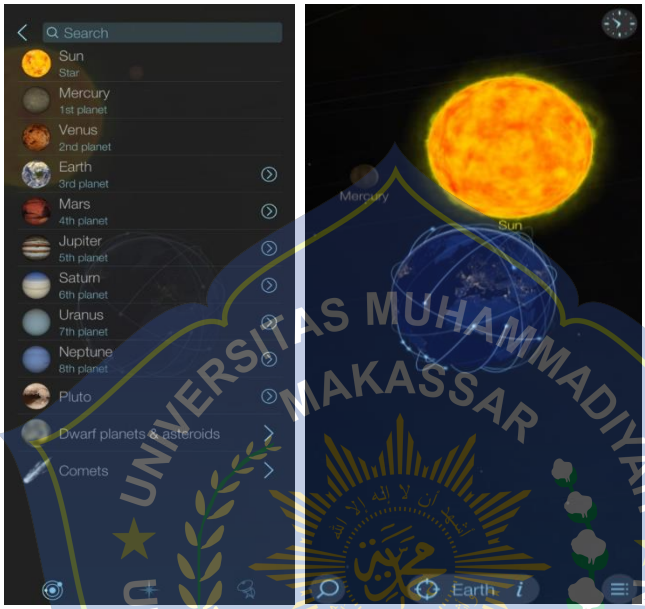

Figure 2. Display of the SkyView Lite Application

The AR-based *SkyView Lite* application was used as an interactive learning medium for the topic of the solar system within the STEM Project-Based Learning (STEM-PjBL) model. Through its search and 3D visualization features, students could explore astronomical objects such as the Sun, planets, dwarf planets, asteroids, and comets in real time. The AR display allowed students to observe the relative positions and orbits of planets, as well as to understand the interrelationships among the components of the solar system. This visualization supported students in developing a deeper conceptual understanding while also fostering critical thinking skills through direct observation, analysis, and data-driven discussions derived from the application.

Previous studies have shown that the integration of AR in science learning, particularly on the topic of the solar system, can enhance student engagement, conceptual understanding, and critical thinking skills (Saputro & Salim, 2023; Çakır & Göksu, 2021). Furthermore, the use of AR as a spatial visualization medium is effective in connecting abstract concepts into concrete and easily comprehensible representations (Abdurrahman et al., 2022).

The primary instruments used for data collection were the critical thinking test and the classroom observation sheet. The critical thinking test was designed to measure students' abilities in analyzing, evaluating, and solving science-based problems. Meanwhile, the

observation sheet was used to record the implementation of classroom learning, including student engagement, peer interaction, and the execution of learning steps in accordance with the AR-PjBL-STEM design. Both instruments underwent validity and reliability testing to ensure that the results obtained were accurate and reliable.

Data Description

Before discussing the results of the analysis, it is important to present a description of the data obtained from both groups. The research sample consisted of 65 students divided into two groups: 32 students in the experimental group, who participated in AR-based learning within the PjBL-STEM framework, and 33 students in the control group, who received conventional instruction. Measurements were conducted through pre-tests and post-tests designed to assess students' critical thinking skills. Table 1 presents the statistical descriptions of the pre-test and post-test scores obtained by both groups:

Table 2. Statistical Description of Pre-test and Post-test Scores

Kelompok	Pre-test Average	Post-test Average	N-Gain
Experimental Group	28,27 (SD = 9,0184)	80,61 (SD = 15,0177)	0,75
Control Group	18,89 (SD = 9,3535)	50,91 (SD = 16,8876)	0,45

From the table above, it can be observed that the experimental group demonstrated a significant improvement from the pre-test to the post-test, with a considerably higher average post-test score compared to the control group. The experimental group achieved an N-Gain value of 0.75, which falls into the high category, while the control group obtained an N-Gain value of 0.45, categorized as medium. The greater improvement in the experimental group indicates the positive impact of using AR in the learning process.

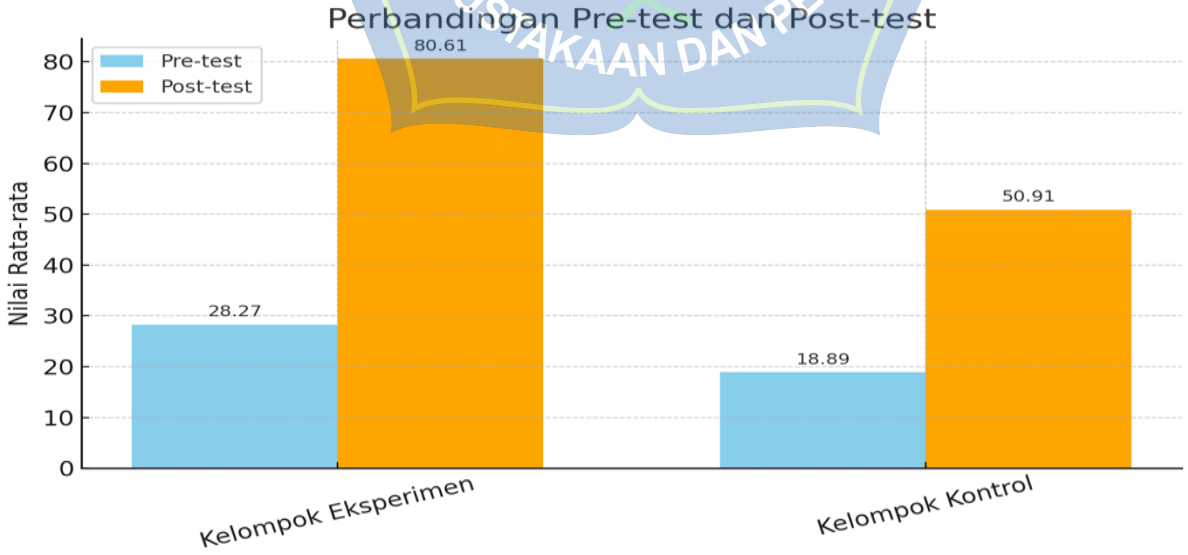

Figure 3. Pre-test and post-test comparison chart

Furthermore, the graph above illustrates a comparison of the average pre-test and post-test scores for the two groups, namely the Experimental Group and the Control Group. The experimental group demonstrated a substantial increase, with the pre-test score rising from 28.27 to a post-test score of 80.61. This considerable difference indicates that the instructional intervention provided to the experimental group was effective in enhancing students' understanding. Meanwhile, the control group also showed an improvement, from a pre-test score of 18.89 to a post-test score of 50.91, although the increase was not as pronounced as that observed in the experimental group.

Pre-test and Post-test Data Analysis

To test the research hypothesis, which posits that the use of AR in STEM-based Project-Based Learning (PjBL) can enhance students' critical thinking skills, an analysis was conducted using the Independent Samples T-Test. This test was employed to compare the differences between the experimental group and the control group after the instructional intervention. Table 2 presents the results of the T-test comparing the post-test scores between the experimental group and the control group:

Tabel 3. T-Test Results for Post-test Scores

Group	**t**	**df**	**Sig. (2-tailed)**
Experimental Group	5,713	63	0,000

The results of the T-test revealed a p-value (Sig. = 0.000) less than 0.05, indicating a statistically significant difference between the experimental group and the control group. This finding suggests that the use of AR in STEM-based Project-Based Learning (PjBL) has a significant positive impact on improving students' critical thinking skills in science learning. The experimental group, which utilized AR, demonstrated a greater improvement compared to the control group.

N-Gain Analysis

In addition to the T-test, an N-Gain analysis was conducted to assess the extent of improvement in students' critical thinking skills following the intervention. N-Gain measures the relative change between pre-test and post-test scores while taking into account the difficulty level of the material taught. The results of the N-Gain analysis showed that the experimental group achieved an N-Gain of 0.75, which falls into the high category, while the control group obtained an N-Gain of 0.45, categorized as medium. Table 3 presents the interpretation of the N-Gain for both groups:

Tabel 4. N-Gain Interpretation of Critical Thinking Skills

Group	**N-Gain**	**Interpretasi**
Experimental Group	0,75	Tinggi
Control Group	0,45	Sedang

The significant improvement observed in the experimental group indicates that the use of AR in STEM-based Project-Based Learning (PjBL) is highly effective in enhancing students' critical thinking skills. In contrast, although there was an improvement in the control group, the increase was smaller and fell within the medium category.

Observation of Learning Implementation

In addition to the critical thinking test, this study also collected data through observation sheets to evaluate the implementation of learning in both groups. The observations were conducted by an experienced science teacher and carried out throughout the entire instructional sessions. Table 4 presents the average scores of learning implementation observed during the instructional process for both groups:

Tabel 4. PjBL-STEM Learning Implementation Score

Group	**Learning Implementation (%)**
Experimental Group	88%
Control Group	75%

The learning implementation score for the experimental group was 88%, indicating that the PjBL-STEM model with AR was well executed in the classroom. Meanwhile, the control group achieved an implementation score of 75%, suggesting that while conventional instruction was carried out effectively, its application was less in-depth compared to the experimental group (Widiyono et al., 2023).

Impact of AR on Students' Critical Thinking Skills

The analysis of the data indicated that the use of AR in STEM-based Project-Based Learning (PjBL) had a significant positive impact on students' critical thinking skills. AR-based learning enabled students to access more interactive and visual materials, which in turn enhanced their understanding of complex concepts. The AR application used in this study, *SkyView Lite*, provided a more immersive learning experience by offering simulations and visualizations of number patterns that are difficult to observe directly in the real world (Alizkan et al., 2021; Akbar et al., 2025). Through the PjBL approach, students not only learned theoretical concepts but also engaged in problem-based projects that required them to collaborate, cooperate, and solve real-world problems (Allanta & Puspita, 2021; R et al., 2023). This approach fosters critical thinking skills as students are required to apply their knowledge in broader contexts and connect theory to practice.

DISCUSSION

The findings of this study indicate that AR-based learning within the PjBL-STEM framework can significantly enhance students' critical thinking skills. This discussion elaborates on the main results, the relevance of the findings, as well as their interpretation and implications for science education.

Enhancing Critical Thinking Skills Through AR and PjBL-STEM

The results obtained from the analysis of pre-test and post-test data show that the experimental group, which used AR in STEM-based PjBL learning, experienced a significantly greater improvement in critical thinking skills compared to the control group, which received conventional instruction. The experimental group achieved a much higher post-test score, with an N-Gain value categorized as high (0.75), whereas the control group was in the medium category (0.45). This demonstrates that the use of AR in STEM-PjBL learning has a positive impact on the development of students' critical thinking skills (Akbar et al., 2025; Putri & Baharun, 2023).

The higher improvement in the experimental group can be explained by the direct interaction afforded by AR. The AR application used in this study, *SkyView Lite*, allowed students to view and interact with science concepts through more immersive visual and simulation formats (Aini et al., 2022; Parno et al., 2022). This provided a more engaging learning experience and helped students better grasp complex material that would be difficult to understand if delivered solely through theoretical explanations. In other words, AR supports students in connecting theory to practice within a more tangible and concrete context, which in turn enhances their critical thinking skills.

The Influence of PjBL-STEM in Science Learning

The PjBL-STEM model, which integrates project-based approaches with the disciplines of Science, Technology, Engineering, and Mathematics, also made a significant contribution to improving students' critical thinking skills. PjBL offers students opportunities to work in groups, solve real-life problems, and produce outputs that can be applied directly. This approach requires students to think analytically and systematically, as well as to solve problems creatively. In this study, students involved in PjBL-STEM did not merely learn theoretical concepts; they were given the opportunity to explore real-world issues, collaborate in teams, and devise applicable solutions. This process actively engaged students in learning, significantly improving their critical thinking skills. Additionally, this approach fosters collaborative and communication skills, which are highly valuable in the professional world.

The Role of AR in Enhancing Student Interaction and Engagement.

One of the primary advantages of AR is its ability to increase student interaction and engagement in the learning process. In this study, the use of AR within PjBL-STEM made learning more dynamic and appealing. Students did not simply listen to the teacher's explanations or read textbooks; they were able to see and directly interact with the objects or phenomena being studied. For example, using *SkyView Lite*, students could observe number patterns in 3D visual form that could be rotated and zoomed in, providing a deeper understanding of the concept. This proved far more effective than merely viewing static representations of number patterns on a whiteboard or in a textbook. Such direct interaction encouraged students to become more actively involved in the learning process, boosting their motivation and attention to the material. This immersive learning experience facilitated better comprehension and deeper analysis of the topics studied.

Comparison with Conventional Learning

The findings of this study also show that the control group, which engaged in conventional learning, demonstrated smaller gains in critical thinking skills, although the improvement was still statistically significant. Conventional instruction generally relies on lectures and practice exercises without leveraging technology or interactive approaches. While such methods remain effective for delivering information, they are less capable of actively engaging students in critical thinking processes. In conventional learning, students tend to memorize information and follow instructions without fully understanding how the concepts apply in real-world contexts. This is evidenced by the study's results, which show that although there was an improvement in critical thinking skills in the control group, the magnitude of the increase did not match that of the experimental group using AR and PjBL-STEM. Therefore, these findings underscore the importance of integrating technology and active learning models into science and STEM education (Allanta & Puspita, 2021; R et al., 2023).

CONCLUSION

This study demonstrates that the use of Augmented Reality (AR) in Project-Based Learning (PjBL) integrated with STEM significantly enhances students' critical thinking skills in science education. The experimental group, which applied AR within the PjBL-STEM framework, exhibited greater improvements in critical thinking skills compared to the control group, which employed conventional teaching methods. These findings highlight the potential of AR as an effective instructional tool for deepening the understanding of abstract scientific concepts while strengthening students' collaboration and problem-solving abilities. This research makes a valuable contribution to the development of more interactive and immersive science learning methods. Moving forward, further studies involving larger samples and a wider range of AR technologies could broaden the understanding of the long-term impact of AR in science education.

RECOMMENDATION

Although this study provides valuable insights, several limitations should be acknowledged. One such limitation is the relatively small sample size, restricted to a single school, which may limit the generalizability of the findings to a broader population. Additionally, the use of AR in learning may be influenced by factors such as students' comfort level with technology or the availability of compatible devices, both of which could affect the effectiveness of AR-based instruction. For future research, it is recommended to conduct studies with larger and more diverse samples, incorporating various types of AR technologies and platforms. Further investigations could also explore the long-term effects of AR-based learning on students' critical thinking skills and the application of their knowledge in real-world contexts.

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Aolika Rahma adalah nama penulis skripsi ini . Penulis lahir dari orang tua Ramlah (ibu) dan Mantega (ayah) sebagai anak ke- Dua dari Tiga bersaudara . Penulis dilahirkan di Sangkulirang Kabupaten Kutai Timur Provinsi Kalimantan Timur pada tanggal 10 Desember 1999. Nama saudari–saudari penulis Aditiawulandani dan Ahmimdal Insyirah Malebbi.

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