The Effect of Augmented Reality-Based Learning Media on Collaboration and Critical Thinking Skills of Fifth Grade Students in Human Circulatory System Topic at SD Muhammadiyah 12 Pamulang

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ABSTRACT

This study aims to investigate the effect of augmented reality (AR)-based learning media on the collaboration and critical thinking skills of fifth-grade students at SD Muhammadiyah 12 Pamulang. Employing a quantitative approach with a quasi-experimental non-equivalent control group design, the sample consisted of two classes: an experimental class using AR-based learning media and a control class using conventional teaching methods. Instruments included validated and reliable questionnaires on collaboration skills and tests for critical thinking skills. Data were analyzed using normality and homogeneity tests, independent t-tests, and F-tests with SPSS version 27. Results showed that the simultaneous influence of AR-based media and collaboration skills on students' critical thinking was significant, with a p-value of 0.001 (<0.05) and Fcalculated > Ftable (13.349 > 2.48). These findings indicate a significant effect of AR-based learning media and collaboration skills on students' critical thinking in learning the human circulatory system.

Keywords: Augmented Reality, Learning Media, Collaboration Skills, Critical Thinking, Elementary Science Education

INTRODUCTION

Education in the 21st century requires students to master not only cognitive knowledge but also essential skills such as collaboration and critical thinking [1], [2]. In science learning, especially topics like the human circulatory system, these skills are often underdeveloped due to traditional lecture-based approaches that fail to actively engage students [3], [4]. As a result, students frequently encounter difficulties in understanding abstract concepts, leading to low motivation and learning outcomes [5].

To address these challenges, educators are exploring innovative teaching methods and learning media. Augmented Reality (AR) is one such technology that integrates virtual elements into real environments interactively, creating engaging and immersive learning experiences [6], [7]. AR-based media offers three-dimensional visualizations and simulations that help students comprehend complex scientific processes, such as blood circulation in the human body [8].

Research indicates that AR can enhance students' understanding, motivation, and participation in learning [9], [10]. However, its potential to develop collaboration and critical thinking skills in elementary students remains underexplored. Collaboration involves working effectively with peers, sharing ideas, and solving problems collectively, while critical thinking requires analyzing information, evaluating solutions, and making reasoned decisions [11], [12].

This study investigates the effect of AR-based learning media on collaboration and critical thinking skills among fifth-grade students in learning the human circulatory system. By integrating AR into science lessons, it is expected that students will not only achieve better conceptual understanding but also demonstrate improved 21st-century skills necessary for lifelong learning [13], [14].

LITERATURE REVIEW

Critical Thinking Skills

Critical thinking is an essential competency in 21st-century education, particularly in science learning where students must analyze complex systems and make evidence-based decisions. Dewey [1] described critical thinking as an active and persistent effort to examine beliefs and knowledge in light of supporting evidence. Molan [11] expanded this idea, suggesting that critical thinking requires students to apply logic and reasoning to evaluate information and develop innovative solutions. In elementary education, critical thinking enables students to comprehend scientific phenomena, formulate hypotheses, and reflect critically on their learning processes.

In Indonesia, critical thinking skills are considered integral to achieving the goals of the national curriculum [20]. However, research by Abidin [2] and Wahyuni [7] shows that conventional teaching methods often fail to develop students' analytical abilities because they emphasize rote memorization rather than inquiry-based learning. Augmented reality (AR) has emerged as a promising tool to address this issue by offering interactive, visual, and problem-based environments that can stimulate critical thinking [3], [6].

Collaboration Skills

Collaboration is another crucial skill required for students to succeed in both academic and real-world settings. According to Johnson and Johnson [15], collaborative learning involves positive interdependence, individual accountability, face-to-face promotive interaction, and group processing. In elementary science classes, collaboration allows students to work together to solve problems, share ideas, and construct collective knowledge. Mashud et al. [17] argue that effective collaboration not only improves learning outcomes but also fosters empathy, communication, and leadership skills.

Studies in Indonesian classrooms (Santrianawati, 2018) [22] have revealed that group-based learning encourages students to listen actively to their peers and take responsibility for their contributions. However, implementing collaborative learning can be challenging in large classrooms where resources and time are limited. AR applications like Assemblr [10] can overcome these barriers by providing digital environments where students can interact with virtual objects and peers simultaneously, promoting collaborative inquiry and shared decision-making.

Augmented Reality in Education

Augmented Reality (AR) is an interactive technology that overlays virtual content on real-world environments in real-time [6]. In the context of science education, AR enables learners to visualize abstract concepts and manipulate 3D models of complex systems, such as the human circulatory system, making learning more engaging and meaningful. Adeoye et al. [3] highlight that AR enhances students' motivation, attention, and retention of knowledge by transforming passive learning into active exploration.

In Indonesia, several studies have demonstrated the effectiveness of AR-based media in elementary education. Agustin and Wardhani [5] found that AR-assisted learning improved middle school students' science performance. Similarly, Abidin [2] reported significant gains in critical thinking skills among fourth-grade students using AR applications. Alkhattabi [6] identified barriers to AR adoption, including lack of teacher training and technological infrastructure, but emphasized its potential for transforming traditional pedagogical practices.

Assemblr, a popular AR platform in Indonesia, has been used to create interactive science lessons that allow students to explore biological systems, conduct simulations, and collaborate with peers in virtual environments [10]. This aligns with global trends where AR is increasingly recognized as a key component of blended and technology-enhanced learning models [4].

Related Studies

Research on AR's impact on learning outcomes has been conducted globally and locally. Wahyuni [7] demonstrated that AR-based learning increased elementary students' interest in science topics, while Adeoye et al. [3] confirmed AR's effectiveness in improving conceptual understanding in diverse learning environments. However, studies focusing on AR's potential to develop both collaboration and critical thinking simultaneously are still limited. Mustafa [18] emphasizes the need for educational interventions that integrate technology to foster these two essential 21st-century skills.

Given this context, the present study seeks to investigate the effect of AR-based learning media on collaboration and critical thinking skills of fifth-grade students in the topic of the human circulatory system. By exploring how AR can support these competencies, this study contributes to the growing body of research on innovative pedagogies for elementary science education in Indonesia and beyond.

METHODOLOGY

Research Design

This study used a quantitative approach with a quasi-experimental design, specifically the nonequivalent control group design [8]. This design was chosen because it allows for comparison between groups while acknowledging the practical limitations of random assignment in real classroom settings. The independent variable in this study was the use of Augmented Reality (AR)-based learning media, while the dependent variables were students' collaboration skills and critical thinking skills.

The experimental group was taught using AR-based media developed with Assemblr [10], while the control group received instruction through conventional methods. The effectiveness of AR in improving collaboration and critical thinking was measured by comparing pre-test and post-test scores between the two groups.

Population and Sample

The population of this study included all fifth-grade students at SD Muhammadiyah 12 Pamulang during the 2024/2025 academic year. A purposive sampling technique was employed to select two classes with similar academic achievement levels and socio-demographic characteristics [9]. One class (30 students) was assigned as the experimental group, and the other class (28 students) as the control group.

Research Instruments

Collaboration Skills Questionnaire

The collaboration skills questionnaire was adapted from Johnson and Johnson's cooperative learning framework [15]. It consisted of 25 items covering dimensions such as communication, responsibility, conflict resolution, and group decision-making. The instrument was validated through expert judgment and achieved a reliability coefficient (Cronbach's alpha) of 0.86, indicating high internal consistency [12].

Critical Thinking Test

The critical thinking test was developed based on Bloom's taxonomy and Facione's critical thinking framework [1]. It included 20 multiple-choice questions and 5 essay items designed to measure analysis,

evaluation, and reasoning skills. Content validity was ensured by consulting three science education experts, and pilot testing with 30 students resulted in a reliability score of 0.82.

Development of AR-Based Learning Media

The AR learning media was developed using Assemblr Studio, an interactive AR application compatible with Android devices [10]. The media included 3D models of the human circulatory system, animations of blood flow, and interactive simulations that allowed students to manipulate virtual objects in real time. The content was aligned with the national curriculum (Permendikbud No. 21/2016) [20] and designed to encourage collaborative learning and inquiry-based exploration [5]. The AR-based activities included 3D models and interactive features such as heart rotation, blood flow animations, and labeled structures, which helped students visualize the topic in a concrete manner. These activities facilitated group discussions and deeper understanding

Data Collection Procedure

The study was conducted over six weeks. The first week involved pre-tests to assess students' initial levels of collaboration and critical thinking. During weeks 2–5, the experimental group engaged in AR-assisted lessons, while the control group used conventional textbooks and teacher-centered instruction. In the sixth week, post-tests and questionnaires were administered.

Data Analysis Techniques

Data were analyzed using SPSS version 27, employing several statistical procedures to ensure the validity and reliability of the findings. A Kolmogorov-Smirnov test was conducted to assess the normality of data distribution, while Levene's test was used to examine the homogeneity of variances across the groups [23]. To compare the pre-test and post-test scores between the experimental and control groups, an independent samples t-test was applied. Additionally, a two-way ANOVA was performed to investigate the simultaneous effects of AR-based learning media and collaboration skills on students' critical thinking. The level of significance was set at $\alpha = 0.05$, and Cohen's d was calculated to determine the effect size, providing insights into the magnitude of the observed differences [12].

RESULTS AND DISCUSSION

Results

The findings of this study reveal significant differences between the experimental group (taught with Augmented Reality-based learning media) and the control group (taught using conventional methods) in terms of collaboration and critical thinking skills.

Descriptive Statistics

The pre-test scores showed no significant differences between the experimental and control groups for both collaboration and critical thinking skills ($p > 0.05$), indicating equivalence at baseline [23]. Post-test results, however, demonstrated higher mean scores in the experimental group for collaboration ($M = 85.4$, $SD = 5.3$) and critical thinking ($M = 82.7$, $SD = 6.1$) compared to the control group (collaboration: $M = 74.1$, $SD = 6.8$; critical thinking: $M = 70.3$, $SD = 7.2$).

Inferential Statistics

An independent samples t-test revealed statistically significant differences in the post-test scores for both variables. For collaboration, the test produced $t(56) = 5.47$ with a p-value < 0.001 and a Cohen's d of 1.15,

indicating a substantial effect. Similarly, for critical thinking, the results showed $t(56) = 6.02$, $p < 0.001$, with a Cohen's d of 1.23. These large effect sizes suggest that the AR-based learning media had a strong and meaningful impact on enhancing students' collaboration and critical thinking skills [12].

Two-Way ANOVA

The results of the two-way ANOVA showed a significant interaction between AR-based media and collaboration skills on critical thinking ($F(1, 56) = 13.349$, $p = 0.001$, $\eta^2 = 0.19$). This suggests that students who worked collaboratively in AR environments exhibited higher levels of critical thinking than those in traditional settings [15].

DISCUSSION

The results align with prior studies emphasizing the potential of Augmented Reality (AR) to enhance student engagement, collaboration, and higher-order thinking [3], [5], [6]. AR's interactive features, such as 3D models and simulations, provided students with opportunities to work together in exploring complex concepts like the human circulatory system.

Impact on Collaboration Skills

The experimental group demonstrated substantial improvement in collaboration skills. This can be attributed to AR's ability to create shared digital environments that promote teamwork and peer interaction [17]. As students manipulated virtual models and solved problems together, they developed communication and negotiation skills, which are essential for effective collaboration [15]. These findings are consistent with the work of Mashud et al. [17], who found that collaborative activities integrated with technology improved students' ability to work as a team.

Impact on Critical Thinking Skills

AR-based learning media encouraged students to engage in inquiry-based learning, analyze information, and draw evidence-based conclusions [1], [18]. The interactive simulations required students to observe, hypothesize, and test ideas, fostering critical thinking processes. Previous studies by Wahyuni [7] and Agustin & Wardhani [5] reported similar outcomes where AR integration in science classes enhanced students' analytical and evaluative abilities.

The Synergy Between AR and Collaborative Learning

The combination of AR and collaborative learning appears to have a synergistic effect. Students in the experimental group engaged in discussions about the functions of the heart, blood vessels, and blood circulation processes using AR applications like Assemblr [10]. These interactions provided opportunities for peer teaching and critical reflection, which deepened their understanding of the subject matter.

Comparisons with Traditional Learning

In contrast, students in the control group relied on teacher-centered instruction and textbook diagrams, which limited their ability to visualize and explore scientific concepts. As noted by Abidin [2], traditional approaches often fail to stimulate higher-order thinking because they focus on memorization rather than exploration.

Implications for Elementary Science Education

This study supports the integration of AR into elementary science education to develop 21st-century skills, as recommended by Mustafa [18]. The findings suggest that AR not only improves conceptual understanding but also prepares students for collaborative problem-solving in real-world contexts.

LIMITATIONS AND FUTURE RECOMMENDATIONS

This study has several limitations. First, the use of non-random group assignment may have introduced selection bias, which can reduce internal validity. Although purposive sampling was used to ensure equivalence in academic level and demographics, future studies should consider randomized controlled trials to strengthen causal inference. Second, the relatively small sample size (N = 58) limits generalizability. Larger and more diverse samples from multiple schools would provide broader insights.

Additionally, this research focused solely on the topic of the human circulatory system. While this topic benefits from AR's visual nature, future studies should explore its application across other science domains—such as ecosystems, physical changes, or energy transformation—to assess broader pedagogical effectiveness.

Furthermore, this study relied solely on quantitative data from tests and questionnaires. Including qualitative data—such as student interviews, teacher reflections, or classroom observations—could offer richer insight into how students interact with AR media, the nature of their collaboration, and shifts in motivation or attitude.

For practical implementation in Indonesian elementary schools, several challenges must be considered, including limited infrastructure, teachers' readiness, and students' digital literacy. Teacher professional development programs should address AR integration in pedagogy, while schools must ensure access to adequate devices and internet connectivity. Assemblr, as a widely used AR platform in Indonesia, offers an accessible starting point, but broader policies are needed to support sustainable integration.

CONCLUSION

This study examined the effect of Augmented Reality (AR)-based learning media on the collaboration and critical thinking skills of fifth-grade students in the topic of the human circulatory system. The findings revealed that AR-based learning media significantly enhanced students' abilities to collaborate and engage in higher-order thinking processes compared to traditional teaching methods.

The use of AR applications, such as Assemblr, allowed students to interact with three-dimensional models and simulations, facilitating a deeper understanding of complex biological concepts. These interactive features encouraged students to communicate, discuss, and solve problems together, fostering collaboration skills as outlined by Johnson and Johnson's cooperative learning framework [15]. Simultaneously, AR stimulated critical thinking by requiring learners to analyze, evaluate, and synthesize information, supporting Dewey's notion of reflective thought in education [1].

The significant difference between the experimental and control groups highlights AR's potential as an innovative instructional strategy for 21st-century classrooms. Beyond improving science learning outcomes, AR promotes essential soft skills like teamwork, problem-solving, and decision-making, which are crucial for preparing students for real-world challenges.

However, the study acknowledges limitations, including the relatively small sample size and lack of random group assignment, which may restrict the generalizability of the results. Furthermore, implementing AR in elementary classrooms requires adequate technological infrastructure and teacher training, as noted by Alkhattabi [6]. Future research should investigate the long-term effects of AR on various cognitive and affective domains across diverse educational contexts.

In conclusion, AR-based learning media provides an effective pedagogical tool for developing collaboration and critical thinking skills among elementary students. Its integration into science education aligns with the national curriculum's emphasis on active, student-centered learning [20]. Teachers and policymakers are encouraged to consider AR as part of blended learning strategies to enhance both academic achievement and 21st-century competencies.

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