Android-based STEM-AR and its contribution to elementary school students' environmental literacy

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ABSTRACT

This study is motivated by the low environmental literacy and academic achievement of elementary school students. The study aims to measure the effect of Android-based STEM-AR on students' environmental literacy. A quantitative research method with a One Group Pretest-Posttest Design was used. A total of 31 fifth-grade elementary school students in Yogyakarta, Indonesia, were randomly selected from nine public schools. The research instruments included a lesson plan and an Augmented Reality (AR) medium accessible via Android smartphones. STEM was used as a reference for structuring subject matter. The treatment was conducted four times, each lasting 70 minutes. Students' environmental literacy was measured before and after the treatment using a validated multiple-choice test. Data analysis employed a t-test with a 5% significance level. The Paired Sample Test results showed a sig(2-tailed) value of 0.001 < 0.05, which led to the rejection of the null hypothesis and acceptance of the alternative hypothesis. This study contributes to proving that Android-based STEM-AR positively influences elementary school students' environmental literacy.

1. Introduction

Science learning has become one of the essential subjects in elementary school. Science plays a crucial role in education as it equips students to face challenges in the global era [1], [2] students to grasp scientific concepts and apply them in daily life [3]. This application is particularly important in understanding and responding to environmental conditions. Ideal science learning should help students comprehend the aspects of their surroundings [4]–[6]. Science learning must also foster students' environmental literacy. It is one of the appropriate solutions to enhance environmental literacy. In the process of science learning, the concept of environmental literacy should be instilled in students. This means that science learning should help students understand their environment. Environmental literacy is a conscious attitude toward maintaining environmental balance [7], [8]. It consists of components focused on knowledge, skills, attitudes, and behaviors. To improve environmental literacy, strategies and understanding of environmental issues are necessary. Environmental issues are a global threat, affecting both developed and developing countries. Environmental and climate change issues are serious topics of discussion. Indifference toward the environment is one of the factors causing environmental damage. Public indifference toward the environment, especially in Java-Bali, Indonesia, is still dominated by waste management and private vehicle usage. Meanwhile, in terms of water conservation, the Special Region of Yogyakarta,

Indonesia, has the highest rate. Environmental pollution in water conservation, private vehicle usage, and waste management has impacted the water cycle. The high level of public indifference toward the environment is due to a lack of environmental literacy. Efforts to cultivate environmental literacy from an early age are necessary. Therefore, as part of society, elementary school students should possess environmental literacy skills.

Environmental issues are urgent problems that need to be addressed. One way to tackle them is through learning assisted by instructional media. Media is a key factor in attracting students to the learning process while raising their awareness of environmental issues. Digital media such as AR, VR, the metaverse, and similar platforms are suitable for today's elementary students, as they can present abstract concepts in a tangible way [9]–[12]. This research will focus on the use of AR, which is more accessible to students in Indonesia due to its ease of use. AR can be accessed on mobile phones with various operating systems. Since Android is more widely used in Indonesia, this research will use an Android-based AR. The AR developed in this study is a STEM (Science, Technology, Engineering, Mathematics)-based media focused on the water cycle, aiming to foster students' environmental literacy by visualizing abstract concepts through AR. The advantages of AR include interactivity, deeper user experiences, increased user engagement, contextual information delivery, and more engaging learning. For teachers, AR can enhance creativity in developing applications. STEM is used as the basis for material development due to its ability to bring real-world environmental issues into the classroom. It bridges the gap between life and school [12], [13]. Students become more connected to their world, making learning more meaningful. One of the strengths of STEM in education is its ability to train students cognitively, skillfully, and affectively. Additionally, students are not only taught theoretically but also practically, allowing them to experience the learning process directly [14]. STEM-based learning also trains students to understand technology, sharpen cognitive and affective skills, and apply knowledge. STEM learning is claimed to enhance critical thinking skills, stimulate student creativity, involve students in the entire learning process, prepare them for future careers, develop collaboration skills, and provide experimental and contextual problem-solving experiences.

Several studies have applied AR and STEM in learning. The impact of AR and STEM has been positive in many cases. The achievement of environmental literacy concepts in classes using Augmented Reality is higher on average compared to classes using conventional learning media [10]. This indicates that Augmented Reality is more effective than conventional learning media. Augmented Reality learning media can create an engaging and enjoyable learning atmosphere. It significantly influences motivation to learn, learning outcomes, learning performance, reduces anxiety levels, and enhances higher-order thinking skills [15]–[17]. These advantages further convince the author to research this field. However, research on AR-STEM focusing on environmental literacy is still limited. While there have been many studies on AR and STEM, this theme remains promising for development. A scientometric analysis of publications in the Scopus database over the past decade using RStudio shows that topics related to AR, STEM, Android, and environmental literacy are still underexplored. Therefore, this study will examine the contribution of AR-STEM to environmental literacy in science learning, specifically on the topic of the water cycle. The findings of this research can significantly contribute to educational innovation, particularly in strengthening the importance of STEM and digital technology as learning media.

2. Method

This study was conducted at Muhammadiyah Ambarketawang I elementary school during the even semester of the 2022/2023 academic year. An experimental method with a One Group Pretest-Posttest Design was used. This design involved administering a pretest before the treatment and a posttest after the treatment to measure its effectiveness. A Simple Random Sampling technique was applied to select 31 students from the population. Data collection was conducted using validated multiple-choice tests of environmental literacy. The validity of test items was determined using the point-biserial correlation, while reliability was assessed using the Kuder-Richardson (KR-21) formula. Data analysis included descriptive statistics and the simple linear regression.

3. Results and Discussion

This study investigates the impact of Android-based STEM-AR on the environmental literacy and science learning outcomes of fifth-grade students at Muhammadiyah Ambarketawang I elementary

school. The findings are presented in an integrated manner to provide a comprehensive understanding of the research results. The environmental literacy of students before and after using Android-based STEM-AR was analyzed using descriptive statistics, as shown in Table 1.

Table 1. Environmental Literacy Data

Description	Pretest	Posttest
Mean	59.19	81.61
Median	60.00	80.00
Mode	50	85
Std. Deviation	12.25	9.94
Minimum	35	55
Maximum	80	100

The application of science concepts is essential for students to understand and respond to their surrounding environmental conditions. Therefore, science learning should help students develop environmental literacy skills. The ideal science learning helps students understand the natural environment and the application of science [18]. However, at Muhammadiyah Ambarketawang I elementary school, students' environmental literacy still needs improvement. Based on the research results, it can be concluded that using Android-based STEM-AR can improve students' environmental literacy. The achievement of environmental literacy concepts in classes using Augmented Reality had a higher average compared to classes using conventional learning media [9]. This study included pretest and posttest activities. The pretest results showed that most students had not yet achieved mastery. The average environmental literacy score in the pretest was 59.19, indicating the need for improvement. After using Android-based STEM-AR, the average score increased to 81.61. The research shows that students' environmental literacy improved due to the application of Android-based STEM-AR. This improvement occurred because of the appropriate use of media and effective delivery of material. This is related to educators' considerations in determining strategies, methods, models, and learning media. Based on the descriptive statistics, categorization was created for each research variable. The results of the environmental literacy categorization are as Table 2.

Table 2. Categorization of Students' Environmental Literacy

Category	Interval	Pretest	*Posttest*
High	> 67	25.9% (8)	93.6% (29)
Moderate	33 - 67	74.1% (23)	6.4% (2)
Low	< 33	0.0% (0)	0.0% (0)
Total		100% (31)	100% (31)

In the aspect of environmental literacy, the indicators include knowledge, attitude, and competence. The analysis results for each indicator are as Fig. 1.

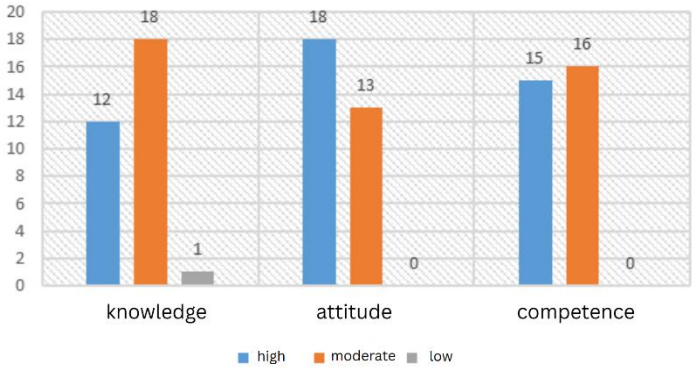

Fig. 1. Results of Environmental Literacy Assessment per Indicator

Android-based STEM-AR played a significant role in improving students' environmental literacy. The pretest results indicated that students had limited understanding, with an average score of 59.19. However, after integrating STEM-AR into learning, the average score increased to 81.61. This finding aligns with previous studies [9], which state that Augmented Reality enhances environmental literacy compared to conventional methods. The data on the science learning outcomes of fifth-grade students at Muhammadiyah Ambarketawang I elementary school using Android-based STEM-AR can be seen in Table 3.

Table 3. Data on Students' Science Learning Outcomes

Description	Pretest	Posttest
Mean	61.45	85.48
Median	65.00	85.00
Mode	65.00	80.00
Std. Deviation	13.42	9.77
Minimum	30.00	60.00
Maximum	80.00	100.00

Based on the descriptive statistics, categorization was created for each research variable. The results of the science learning outcomes categorization are as Table 4.

Table 4. Categorization of Students' Science Learning Outcomes

Category	Interval	Pretest	*Posttest*
High	> 67	38.8% (12)	96.8% (30)
Moderate	33 - 67	58.0% (18)	3.2% (1)
Low	< 33	3.2% (1)	0.0% (0)
Total		100% (31)	100% (31)

In the aspect of science learning outcomes, the indicators include understanding the water cycle (indicator 1), types of water cycles (indicator 2), elements in the water cycle (indicator 3), stages of the water cycle (indicator 4), and activities to maintain the sustainability of the water cycle (indicator 5). The results of the analysis for each indicator are shown in Fig. 2.

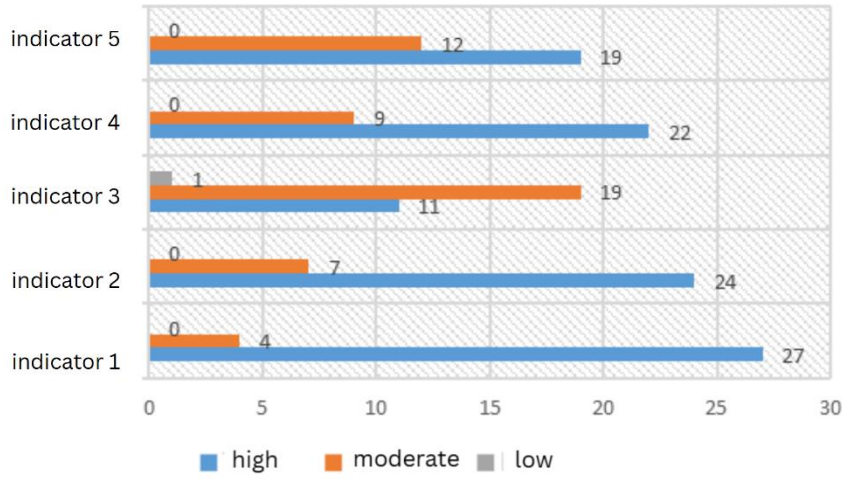

Fig. 2. Results of Science Learning Outcomes Assessment per Indicator

Science learning at Muhammadiyah Ambarketawang I elementary school has been running well, but the use of technology-based learning media still needs to be improved. The learning media used will certainly influence students' science learning outcomes. Teaching science through memorization or writing methods makes it difficult for students to understand the material. This is supported by the teacher's statement that learning outcomes in the water cycle material need improvement. Based on the research results, it can be concluded that using Android-based STEM-AR can improve students' science learning outcomes. Augmented Reality learning media significantly influences students' motivation and learning outcomes [16]. This study included pretest and posttest activities. The pretest results showed an average science learning outcome score of 61.45, indicating the need for improvement. The posttest results showed an increase in students' science learning outcomes. After using Android-based STEM-AR, the average science learning outcome score increased to 85.48. Android-based STEM-AR is expected to provide positive stimulation to students, enabling them to understand the material more easily and improve their learning outcomes. This study used data analysis to test the proposed hypotheses. The data analysis methods used in this study include normality tests, linearity tests, and hypothesis testing. Table 5 shows the results of the normality test for fifth-grade students' environmental literacy and science learning outcomes.

Table 5. Normality Test Results

Data	Shapiro-Wilk			Conclusion
	Statistic	*Df*	*Sig.*	
Pretest Environmental Lit.	0.964	31	0.381	Normal
Posttest Environmental Lit.	0.965	31	0.382	Normal
Pretest Science	0.945	31	0.112	Normal
Posttest Science	0.950	31	0.160	Normal

Hypothesis testing in this study used a paired sample t-test with the help of SPSS. The significance level was set at 5%. The results of the hypothesis testing using SPSS can be seen in Table 6.

Table 6. Paired Sample T-Test for Environmental Literacy and Learning Outcome

	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Significance	
				Lower	*Upper*			*One-Side p*	*Two-Side p*
Pair 1: Environmental Literacy	-22.581	13.957	2.507	-27.700	-17.461	-9.008	30	<.001	<.001
Pair 2: Learning Outcome	-24/032	12.478	2.241	-28.609	-19.455	-10.723	30	<.001	<.001

After hypothesis testing, the next step was to conduct a simple linear regression test using an F-test. Table 7 shows the results.

Table 7. Model Summary of Simple Linear Regression for Environmental Literacy

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Environmental Literacy	.714	.510	.502	11.161
Learning Outcome	.721	.520	.512	11.746

Based on the 2nd row of Table 7, the correlation value (R) is 0.714, and the coefficient of determination (R^2) is 0.510, meaning that 51% of the dependent variable is influenced by the independent variable. Therefore, Android-based STEM-AR media has a 51% influence on environmental literacy, while the remaining 49% is influenced by other factors. From 3rd row, the correlation value (R) is 0.721, and the coefficient of determination (R^2) is 0.520, meaning that 52% of the dependent variable is influenced by the independent variable. Therefore, Android-based STEM-AR media has a 52% influence on science learning outcomes, while the remaining 48% is influenced by other factors. Based on the results of quantitative experimental research, it was found that Android-based STEM-AR significantly influences the environmental literacy of fifth-grade elementary school students. The research results showed a better improvement in environmental literacy. Based on the t-test analysis, the significance value was 0.001, meaning that the ANOVA table showed a significance value of $0.001 < 0.05$. Therefore, it can be concluded that H_0 is rejected, and H_a is accepted. Thus, there is a significant influence of Android-based STEM-AR media in science learning on the environmental literacy of fifth-grade elementary school students. Based on the author's observations, students' environmental literacy still needs improvement. One effort to improve environmental literacy is through integration into learning. The use of STEM-based AR should be utilized as a means to enhance students' environmental literacy. STEM-based learning can train students to understand technology, sharpen cognitive and affective skills, and apply knowledge.

The use of AR in education can stimulate students' critical thinking about problems and events in their environment or daily lives [19]–[21]. This supports how STEM-based AR can influence students' environmental literacy. During the research, it was observed that students could apply their learning and think more critically about environmental or everyday issues. This is supported by the improvement in test results. The influence of Android-based STEM-AR on environmental literacy was 51%, while the remaining 49% was influenced by other factors. Several factors can influence students' environmental literacy. Factors influencing students' environmental attitudes include daily habits at home, self-awareness of environmental care, students' knowledge, and exposure to environmental organizations [8], [22]–[24]. Based on the results of quantitative experimental research, it was found that Android-based STEM-AR significantly influences the science learning outcomes of fifth-grade elementary school students. The research results showed a better improvement in students'

learning outcomes. Based on the t-test analysis, the significance value was 0.001, meaning that the ANOVA table showed a significance value of 0.001 < 0.05. Therefore, it can be concluded that H_0 is rejected, and H_a is accepted. Thus, there is a significant influence of Android-based STEM-AR media in science learning on the science learning outcomes of fifth-grade elementary school students. The research results showed a difference between pretest and posttest scores in students' science learning outcomes. The improvement in test scores after using Android-based STEM-AR was due to students finding the learning process more engaging, active, and enjoyable. As a result, students could better remember the material. This was evident during the learning process. The application of STEM-AR concepts can enhance students' reasoning and imagination [25], [26]. STEM-based learning can connect and integrate scientific knowledge with real-life phenomena [14], [27].

4. Conclusion

This study reveals that Android-based STEM-AR significantly enhances environmental literacy and science achievement among elementary school students. The increase in test scores suggests that STEM-AR serves as an effective tool for improving both environmental literacy and science learning outcomes. These findings highlight the potential of digital learning media in enhancing student engagement and comprehension in STEM education. The implications of these findings for educational practice include the broader adoption of augmented reality-based technology in science learning, which can help students grasp concepts more deeply through interactive experiences. In the realm of educational policy, this study underscores the need for a more systematic integration of digital technology into the science curriculum to enhance learning effectiveness. As practical recommendations, teachers can adopt STEM-AR as an interactive teaching aid to boost student motivation and understanding. Policymakers should consider developing policies that support the adoption of innovative technology in education, including training programs for teachers to optimize the use of STEM-AR. Future research should further explore the long-term effectiveness of STEM-AR and its adaptation across various learning contexts to strengthen the findings obtained.

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Declarations

Author contribution : D.M.N. conceptualized the study and led the manuscript writing. I.M. coordinated the curriculum design and provided feedback on the instructional alignment of the STEM-AR content. C.J.S. contributed to the development of learning media and data collection in the classroom. D.S. supervised the experimental methodology and performed data validation. T.W. was responsible for statistical data analysis and graphical visualization. A.B.S. contributed to the theoretical framework and literature review refinement. All authors reviewed and approved the final version of the manuscript.

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