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Innovation Augmented Reality-Based E-Magazine to Improve Students' STEM Literacy in Human Excretory System Learning

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Abstract. The rapid development of information and communication technology in Industry 4.0 has transformed education and requires innovative learning approaches to develop students' 21st-century skills, particularly STEM literacy. Indonesian students still demonstrate low achievement and engagement in STEM learning, as well as a lack of interactive digital learning resources. This study aims to evaluate the effectiveness of an Augmented Reality-Based E-Magazine (E-Magazine AR) as an innovative learning resource for the human excretory system material, to improve students' STEM literacy. The research employed a one-group pretest-posttest experimental design involving eighth-grade students of Junior High School 27 Semarang. Data were collected using STEM literacy tests administered before and after the learning intervention. The results showed a significant improvement in students' STEM literacy, with an N-Gain score of 0.77 (from 59.12 in the pretest to 91.32 in the posttest), categorised as high. The paired sample *t-test* also indicated a significant difference ($p < 0.05$), confirming the effectiveness of the E-Magazine AR. Additionally, 91% of students achieved very high criteria after the intervention. These findings indicate that the E-Magazine AR is an effective digital learning media for enhancing students' STEM literacy. This research supports SDGs 4 on quality education by promoting innovative digital learning in science education. It also contributes to SDGs 9 by advancing the digitalization of educational infrastructure through the integration of AR technology into E-Magazine learning media. The findings contribute to science education by providing an interactive and scalable learning solution that enhances students' understanding, engagement, and readiness for a technology-driven learning environment.

Keywords: Augmented Reality; E-Magazine; Human Excretory System; Science Learning; STEM Literacy

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INTRODUCTION

The rapid development of information technology and artificial intelligence in the era of Industry 4.0 has significantly transformed various sectors, including education. This transformation requires education systems to prepare students with strong adaptability and competitiveness in a global context (Moraes et al., 2023; Parmin et al., 2024; Crețu et al., 2025; Kumar, 2025). Consequently, the development of 21st-century skills (critical thinking, creativity, communication, and collaboration) has become a central focus in modern education (Boleng et al., 2018; Sharma et al., 2025; Mukul & Büyüközkan, 2023; Thornhill-Miller et al., 2023).

In this context, STEM literacy has emerged as an essential competency that enables students to integrate knowledge from science, technology, engineering, and mathematics to solve real-world problems and develop innovations (Rahmi & Kaban, 2023). STEM literacy is closely associated with STEM education, which emphasizes interdisciplinary learning and the application of knowledge in authentic contexts (Mohr-Schroeder et al., 2020; Jackson et al., 2021; Falloon et al., 2022; Xu et al., 2025). However, Indonesian students still demonstrate relatively low achievement in science and mathematics, as reflected in the 2022 PISA results (OECD, 2022).

This issue is further supported by observations among eighth-grade students at Junior High School 27 Semarang, who show limited ability to connect scientific concepts with real-world STEM applications and low engagement in problem-solving activities (Tan et al., 2023).

Despite the implementation of the national curriculum in Indonesia, which encourages the integration of technology in learning, the use of digital learning media in schools remains limited. Science learning is still largely dominated by textbooks and basic presentation tools, which tend to be less interactive and fail to stimulate students' curiosity (Semma et al., 2024; Kumar, 2025; Yaseen et al., 2025). This limitation becomes more critical in topics such as the human excretory system, where students often struggle to understand abstract concepts due to the lack of effective visualization (Etobro & Fabinu, 2017; Gilissen et al., 2021; Didier et al., 2025).

Augmented Reality (AR) has been widely recognized as an innovative technology that can address these challenges by providing interactive and real-time 3D visualizations, thereby enhancing students' conceptual understanding and engagement in science learning (Alper et al., 2021; Teplá et al., 2022; Zhou et al., 2022; Mansour et al., 2025). Moreover, AR aligns with the learning preferences of Generation Z students, who tend to favor visual, technology-based, and self-directed learning environments (Hernandez-de-Menendez et al., 2020; Vizcaya-Moreno & Pérez-Cañaveras, 2020; Jiang et al., 2025). Integrating AR with digital learning media, such as E-Magazines, can create interactive, engaging, and accessible learning experiences.

Previous studies have demonstrated the effectiveness of various technology-enhanced approaches in improving STEM literacy. For instance, Mohafa et al. (2022) reported that online STEM laboratories significantly enhanced students' STEM literacy in stoichiometry, while Widiyatmoko et al. (2023) found that Virtual Reality Game-Based Learning (VRGBL) improved students' STEM literacy in energy concepts. Additionally, Chen et al. (2025) confirmed that STEM education has a positive impact on students' STEM literacy. However, most existing studies focus on either AR technology or STEM literacy separately, with limited research integrating both within a comprehensive and interactive learning media, such as an AR-based E-Magazine, particularly in the context of the human excretory system material.

To address this gap, this study introduces an Augmented Reality-Based E-Magazine (E-Magazine AR) as an innovative learning resource designed to improve junior high school students' STEM literacy. By integrating AR technology with structured STEM learning content, this study provides a more immersive and meaningful learning experience. Therefore, the research question of this study is: How effective is the implementation of an E-Magazine AR in improving junior high school students' STEM literacy in learning the human excretory system? This study aims to evaluate the effectiveness of an E-Magazine AR in improving junior high school students' STEM literacy in learning the human excretory system material.

The findings of this study are expected to contribute to science education by offering an innovative, interactive, and scalable digital learning solution that enhances students' conceptual understanding, engagement, and readiness for 21st-century learning. Furthermore, this research provides practical implications for educators in integrating emerging technologies into classroom instruction to support meaningful STEM learning experiences and contribute to SDGs 4 and 9.

METHODS

Research Design

This study employed a one-group pretest-posttest design (Sugiyono, 2024), in which a single class was assigned as the experimental group (see Figure 1). Before the intervention, participants completed a pretest to assess their initial STEM literacy level. They then participated in science learning using the E-Magazine AR, which consisted of five meeting focused on the human excretory system material to help students comprehend its structure, function, and processes. At the end of the intervention, participants completed a posttest using the same instrument (Arikunto, 2018).

Figure 1. One-Group Pretest-Posttest Design Research

Participants

This study was conducted at Junior High School 27, Semarang, Central Java, Indonesia. The participants consisted of eighth-grade students enrolled in science classes covering the human excretory system material. A total of 34 students from a single class were selected using a purposive sampling technique.

Data Collected

A STEM literacy test consisting of 20 multiple-choice items with reasoning was used to measure students' STEM literacy before and after the implementation of the E-Magazine AR in science learning activities on the human excretory system. Before use, the test instrument was analyzed to determine its validity, reliability, level of difficulty, and item discrimination index for each item. The development of the STEM literacy test was based on indicators proposed by Tang & Williams (2019) and Suwarma et al. (2023), namely: 1) Explaining scientific phenomena; 2) Interpreting scientific data and evidence, 3) Understanding technological principles, 4) Developing solutions and achieving goals, and 5) Formulating situations mathematically. An example of the STEM literacy test is shown in Figure 2.

Science Literacy

1. The formation of urine in the kidneys occurs through several stages, namely filtration, reabsorption, and augmentation. These processes ensure that waste substances are excreted while essential substances are reabsorbed, resulting in the formation of final urine containing metabolic waste. Observe the following picture of the nephron in the kidney.

Picture of kidney nephron
(source: roboguru.ruangguru.com)

The part of the kidney labeled X is the picture where the following process occurs....

A. Filtration in the glomerulus
B. Augmentation in the distal tubule
C. Reabsorption in the proximal tubule
D. Augmentation in the collecting duct

The correct reason for this answer is:

A. The process of filtering blood from waste substances
B. The process of hormone production to regulate blood pressure
C. The reabsorption of substances needed by the body
D. The collection of final urine before excretion

Technology Literacy

2. Observe the following image.

Picture of sweat sensor watch
(source: malangposcomedia.id)

The image shows an example of technological advancement, namely a sweat sensor watch used to monitor body health. The basic working principle of the sweat sensor is related to the function of the skin in the human excretory system, which is....

A. Regulating sweat production
B. Measuring changes in skin temperature
C. Removing toxins from the body
D. Detecting chemical substances in sweat

The correct reason for this answer is:

A. Because the sweat sensor controls the activity of sweat glands
B. Because the sweat sensor detects temperature changes produced by the body
C. Because the sweat sensor helps maintain body temperature balance
D. Because the sweat sensor detects waste substances such as salts and urea in sweat

Engineering Literacy

3. Observe the following image.

Picture of a simple lung model
(source: YouTube Bunda IRA)

In designing a simple lung model as shown above, several aspects must be considered to accurately simulate respiratory function. A student modifies the model by adding a second balloon to represent a diseased lung. If one of the balloons is damaged or leaking, what is most likely to happen to the model?

A. Both balloons will stop functioning because air cannot enter the bottle
B. Air will not enter the model, so no breathing simulation will occur

Mathematics Literacy

4. A patient named Icha visited the hospital for a routine medical check-up. The doctor ordered a blood test to measure her bilirubin level after she reported symptoms such as yellowish skin and fatigue. The following results were obtained:

Parameters	Test Results	Normal Range
Bilirubin Level	3.2 mg/dL	0.3 - 1.2 mg/dL
Blood Volume	5 liters	

Based on this information, what is the amount of excess bilirubin in Icha's body (in mg)?

A. 50 mg
B. 60 mg
C. 90 mg
D. 100 mg

C. The remaining balloon will still function, but the volume of incoming air will be reduced D. The air pressure in the bottle will increase, preventing the healthy balloon from inflating The correct reason for this answer is: A. Because the leaking balloon simulates a decrease in oxygen volume during inspiration B. Because both balloons function as a fully dependent system, if one is damaged, the other cannot function C. Because the leaking balloon increases airflow into the bottle, similar to an infected lung increasing breathing rate D. Because the leaking balloon represents a non-functioning lung, resulting in a decrease in overall lung capacity	The correct reason for this answer is: A. Excess bilirubin has a fixed amount in each person regardless of blood volume B. The liver produces the same amount of bilirubin regardless of measured levels C. Blood volume does not affect the amount of excess bilirubin D. Excess bilirubin is calculated by subtracting the normal level from the measured level and multiplying it by blood volume, indicating the amount that accumulates in the blood

Figure 2. Example of a STEM Literacy Test

Data Analysis

The pretest and posttest data were analyzed using the N-gain test (Hake, 1999) to determine the level of improvement in students' STEM literacy. Data normality was assessed using the Shapiro-Wilk test to ensure the appropriateness of the statistical procedures. Furthermore, a paired-sample *t-test* was conducted to examine whether there was a significant difference in students' STEM literacy before and after the implementation of the E-Magazine AR. In addition, students' STEM literacy profiles were analyzed based on posttest results across four indicators, science, technology, engineering, and mathematics literacy, and categorized into five levels: very high, high, moderate, low, and very low.

RESULTS AND DISCUSSION

The E-Magazine AR is an interactive digital learning resource designed to support students in learning the human excretory system material. One of the key features and novelties of this study is the use of markerless Augmented Reality (AR) technology, which enables students to access 3D models of excretory organs, such as the kidneys, lungs, liver, and skin, through a link without the need for physical markers. In addition, another novelty of this study lies in the integration of text, videos, quizzes, and multiple STEM literacy aspects in one interactive learning media. Unlike previous studies that often focus on only one literacy aspect or use a conventional E-Magazine with AR using markers, this research specifically examines the effectiveness of E-Magazine AR in improving students' STEM literacy across indicators in science, technology, engineering, and mathematics. As shown in Figure 3, this media can be accessed across various devices through mobile platforms (Android and iOS), enabling optimal interactivity and smoother AR performance.

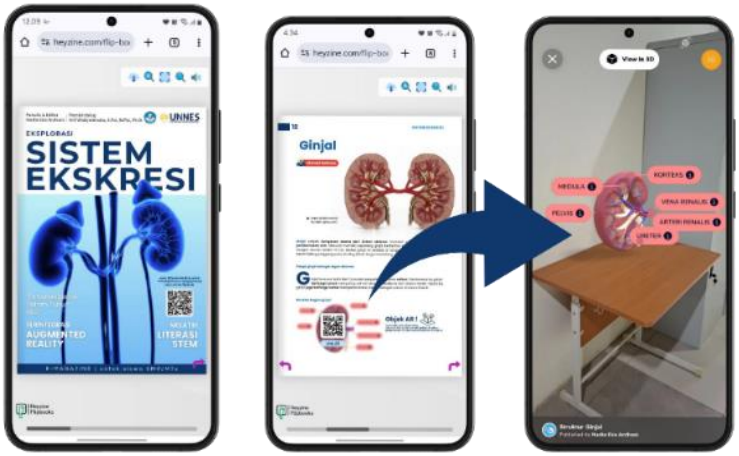

Figure 3. E-Magazine AR Display on Smartphones

Table 1. N-Gain Test Results on STEM Literacy Indicators

STEM Literacy Indicators	Pretest Average Score	Posttest Average Score	N-Gain	Criteria
Science Literacy	56.18	95.29	0.90	High
Technology Literacy	62.06	93.53	0.80	High
Engineering Literacy	57.06	85.29	0.61	Moderate
Mathematics Literacy	61.18	91.18	0.80	High
Average	59.12	91.32	0.77	High

The average pretest and posttest scores from the STEM literacy test were analyzed using the N-Gain Test to measure improvement in students' STEM literacy and the paired-samples *t-test* to determine significant differences in students' STEM literacy before and after using the E-Magazine AR. In addition, we analyzed students' STEM literacy profiles for each indicator. The N-Gain test results showed an increase in the average pretest and posttest scores after using the E-Magazine AR in the human excretory system material. The average pretest score of 59.12 increased to 91.32 on the posttest, with an N-Gain value of 0.77, which is classified as high. The N-Gain values for each STEM literacy indicator are presented in Table 1.

Table 1 displays the N-Gain test results for STEM literacy indicators developed by Tang & Williams (2019). The gain is identified across three indicators with high criteria and one with moderate criteria. The highest gain is in science literacy, which is 0.90 for high criteria. The lowest is engineering literacy, at 0.61 for moderate criteria. The average score increases from pretest to posttest after applying E-Magazine AR, indicating that E-Magazine AR with content on the human excretory system can improve STEM literacy skills among junior high school students.

A significant difference in students' STEM literacy before and after using the E-Magazine AR was analyzed using a paired-samples *t-test*, after confirming data normality with the Shapiro-Wilk test ($\alpha = 0.05$). The results indicated that both pretest (sig = 0.094) and posttest (sig = 0.064) data were normally distributed. The *t-test* scores for each STEM literacy indicator are presented in Table 2. The sig value. (p-value) $< \alpha = 0.05$; meaning these results indicate that the E-Magazine AR on human excretory system material developed is significantly effective for improving STEM literacy of junior high school students.

The analysis of students' STEM literacy profile refers to the average posttest STEM literacy test score. The results of the analysis of students' STEM literacy profiles for each STEM literacy indicator are shown in Figure 4. It shows that the STEM literacy of junior high school students in learning science material on the human excretory system using E-Magazine AR is classified as very high with a percentage of 91% with very high criteria, where science literacy is 95% (very high), technology literacy is 94% (very high), engineering literacy is 85% (high), and math literacy is 91% (very high). These results indicate that most students have strong STEM literacy after using E-Magazine AR on material about the human excretory system in science instruction.

Table 2. Paired Sample *T-test* Results on STEM Literacy Indicators

STEM Literacy Indicators	Test	Average Score	Sig. (2-tailed)
Science Literacy	pretest	56.18	0.00
	posttest	95.29	
Technology Literacy	pretest	62.06	0.00
	posttest	93.53	
Engineering Literacy	pretest	57.06	0.00
	posttest	85.29	
Mathematics Literacy	pretest	61.18	0.00
	posttest	91.18	

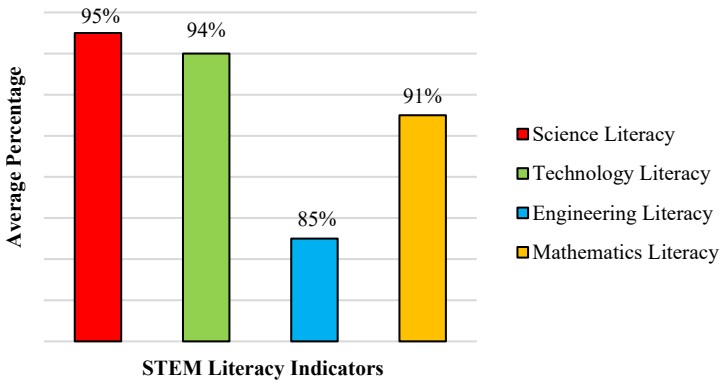

Figure 4. Results of Students' STEM Literacy Profiles on Each Indicator

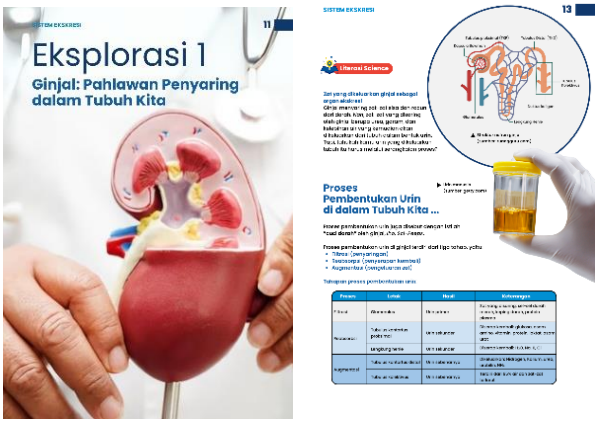

Figure 5. Science Literacy Content in E-Magazine AR

Science literacy, as STEM literacy's first aspect, is more concerned with students' skills in identifying scientific questions, providing accounts of phenomena based on evidence, and interpreting scientific data (Tang & Williams, 2019; Suwarma et al., 2023). In the E-Magazine AR, science literacy skills are reinforced through exploration themes on scientific phenomena, data, and the human excretory system. For instance, in Figure 5, Exploration 1: Kidney, the structure, function, and mechanisms of urine formation (filtration, reabsorption, augmentation) within the kidney are displayed. The N-Gain score for science literacy is 0.90 (high criteria), and the result is verified by the paired-samples *t-test* ($p = 0.00 < 0.05$), indicating that science literacy skills are significantly improved through the use of the E-Magazine AR.

The science literacy profile of eighth-grade students of Junior High School 27 Semarang is very high, with a score of 95%. The results indicate that the eighth-grade students of Junior High School 27 Semarang have been able to respond appropriately and sufficiently to science literacy questions. The results indicate that the use of E-Magazine AR effectively increases science literacy indicators among junior high school students. This aligns with research by Fajri et al. (2025), who found that the Eco Explorer E-Magazine, with a contextual approach, can improve students' science literacy regarding Indonesian ecology and biodiversity materials.

Technology literacy, the second aspect of STEM literacy, involves students' understanding of technological concepts and the development and application of technology in practical situations (Tang & Williams, 2019; Suwarma et al., 2023). In the E-Magazine AR, this type of literacy was promoted through exploration activities that linked subjects on the human excretory system with corresponding technologies. A discussion of a specific example from Figure 6, Exploration 3: Liver, on the FibroScan technology, which is used as a diagnostic method for assessing liver damage from cirrhosis, shows that it has an N-Gain of 0.80 for technology literacy. This met the high criteria and a paired-samples *t-test* with $p = 0.00$, which is significant since $p < 0.05$, shows that E-Magazine AR improved students' technology literacy.

Figure 6. Technology Literacy Content in E-Magazine AR

Figure 7. Engineering Literacy Content in E-Magazine AR

The profile of technology literacy among eighth-grade students at Junior High School 27 Semarang is very high, with a score of 94%. The findings show that the students can correctly and appropriately address solutions, analysis, and responses to tasks in technology literacy. The findings imply that learning with the E-Magazine AR tool has been effective in developing STEM literacy among junior high school students, as evidenced by indicators of technology literacy skills. This result supports the conclusion obtained by Zufahmi et al. (2025), who showed that TPACK-based E-Magazine learning media can improve students' technology literacy in physics material on rotational dynamics and the equilibrium of rigid bodies.

The third aspect of STEM literacy is engineering literacy, which involves the ability to apply scientific and mathematical principles to systematically and creatively design and create practical solutions (Tang & Williams, 2019; Suwarma et al., 2023). In the context of the E-Magazine AR, this literacy is developed when students follow tasks that teach them how to design simple models of the human excretory system. For example, the description in Figure 7, Exploration 2: Lungs, asks students to design a simple model of a lung that demonstrates how respiration occurs. The N-Gain value for engineering literacy is 0.61 (moderate criteria), with a significant result from the paired-samples *t-test* ($p = 0.00 < 0.05$), indicating that the use of the E-Magazine AR improves engineering literacy skills.

The engineering literacy profile of students in eighth grade at Junior High School 27 Semarang is classified as high, with an 85% score. Based on the results, students in eighth grade at Junior High School 27 Semarang began to understand and apply engineering concepts to solve problems. However, they still need guidance in developing more complex solutions. These results show that E-Magazine AR is effective in improving junior high school students' STEM literacy, particularly in engineering literacy. Similar results were reported by Gordon et al. (2023), who found that interactive E-Books improved students' engineering literacy through digital engagement. Likewise, Vonti et al. (2024) demonstrated that a bilingual E-Magazine significantly increased students' digital literacy and conceptual understanding. Although the focus differs, both studies support the idea that interactive digital media can effectively foster engineering literacy.

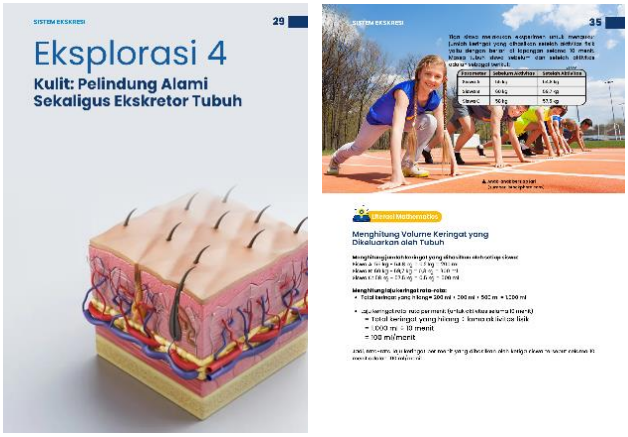

Figure 8. Mathematics Literacy Content in E-Magazine AR

The fourth aspect of STEM literacy is mathematics literacy. This involves the ability to create and solve problems using mathematical thinking (Tang & Williams, 2019; Suwarma et al., 2023). This form of literacy was developed in E-Magazine AR through tasks that asked students to apply math concepts to the human excretory system. This is shown in Figure 8, where students in Exploration 4: Skin calculated sweat production during physical exercise using formulas. The results of the mathematics literacy in E-Magazine AR showed that the N-Gain score was 0.80 (high criteria), and the paired-samples *t-test* also yielded $p = 0.00$, which was significant ($p < 0.05$).

The mathematics literacy profile for eighth-grade students at Junior High School 27 Semarang has a very high classification, with a 91% result. The results show that students can solve problems that involve mathematical formulation. In addition, the results indicate that E-Magazine AR can effectively improve STEM literacy among junior high school students, as measured by indicators of mathematics literacy. This result supports findings from studies by Abd Algani & Gross (2024), which showed that learning using E-Magazine media can effectively develop students' mathematics literacy.

The Augmented Reality (AR) features integrated in the E-Magazine offer interactive 3D visualizations that help students better understand the structure and functionality of organs in the human excretory system. Using a markerless AR technique, students are granted access using mere hyperlinks, hence doing away with the use of markers, which are impractical. Upon opening, students can project 3D models of various organs, such as kidneys, lungs, liver, and skin, into their environment, allowing them to visualize better and understand their own excretory systems (Teplá et al., 2022). This interactive tool offers students a better means of conceptual understanding, as they can engage with computer models of natural phenomena in a hands-on manner (Xiang et al., 2022). In addition, E-Magazine AR offers students a comprehensive understanding of their subjects in a lucid manner, complemented by alluring imagery that aids comprehension and encourages students to read. Visual concepts and imagery are known to be instrumental in providing understanding of concepts and also known to induce reading in students, hence making E-Magazine AR a perfect reading platform for students to improve their literacy skills and performance in class (Ebadi & Ashrafabadi, 2022; Morfidi & Iatraki, 2025; Şimşek et al., 2025).

This research also contributes to science education by providing empirical evidence that an E-Magazine AR can improve students' STEM literacy, particularly in learning abstract concepts related to the human excretory system. The study also contributes to advancing digital learning innovation by demonstrating that integrating AR technology with literacy-oriented content can create a more engaging and meaningful learning experience. In practical terms, this research benefits society, especially educators and schools, by offering innovative instructional media that support student engagement, strengthen literacy competencies, and prepare learners to meet the demands of 21st-century education and technology-driven learning environments. Furthermore, this research supports the Sustainable Development Goals (SDGs), particularly SDGs 4 (Quality Education), by promoting the use of innovative digital learning media to improve students' literacy and learning outcomes. It also supports SDGs 9 (Industry, Innovation, and Infrastructure) through the application of Augmented Reality as a

technological innovation into E-Magazine learning media in educational practice.

CONCLUSION

The results show that using E-Magazine AR significantly improves students' STEM literacy across all aspects (science, technology, engineering, and mathematics). The findings include a high N-Gain score of 0.77 and paired-samples *t-test* significance value of 0.00 ($p < 0.05$). Additionally, 91% of students achieved very high criteria after the intervention. The lowest N-Gain score was 0.61 (moderate criteria) in the engineering literacy aspect, while the highest N-Gain score was 0.90 (high criteria) in the science literacy aspect. This demonstrates that the E-Magazine AR is an effective learning resource for improving students' STEM literacy, particularly in learning the human excretory system. Through the use of the E-Magazine AR, students develop a better understanding of scientific concepts, technological applications, engineering design, and mathematical reasoning, enabling them to apply their knowledge in solving real-world problems. Therefore, the E-Magazine AR serves as an effective digital learning resource that can significantly improve STEM literacy among junior high school students. Future studies are recommended to involve larger and more diverse samples to enhance the generalizability of the findings. In addition, further research could focus on developing similar E-Magazine AR for other science topics to examine their effectiveness in different learning contexts.

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AUTHOR CONTRIBUTION STATEMENT

NEA-data curation, data analysis, research design, writing; AW-supervising, reviewing; AR-supervising, reviewing; TDW-data curation, reviewing; HZ-reviewing, proofreading.

CONFLICT OF INTEREST STATEMENT

All authors have no conflicts of interest to disclose.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that used Artificial Intelligence (AI)-assisted technology, specifically Grammarly to improve grammar and language clarity in this article.

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