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Augmented Reality Flashcards for Enhancing Science Literacy and Academic Therapy in Mangrove Ecosystem Learning: A Participatory Action Research Study

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ABSTRACT

This community service initiative responds to low science literacy among coastal students, specifically on mangrove ecosystems, due to a lack of contextual learning media. Using a Participatory Action Research (PAR) approach over 10 weeks with teachers and students at MA Raudhatul Islamiyah Pembengis, West Tanjung Jabung, this study developed and tested the effectiveness of Augmented Reality (AR) Flashcards. Academic therapy, here referring to targeted pedagogical interventions to reduce learning barriers and enhance cognitive engagement, was integrated into the process. Results show a significant improvement in science literacy, with a 65% increase in conceptual understanding and a 58% rise in analytical skills. The program also enhanced teachers' competence in creating innovative media and established a sustainable practitioner community. The integration of PAR with AR technology proves to be an effective, innovative strategy for advancing science literacy and academic support in coastal areas. This approach demonstrates strong potential for replication in other coastal and resource-limited educational contexts.

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INTRODUCTION

Education in Indonesia faces complex challenges in preparing the younger generation to meet the demands of the 21st century, particularly in coastal regions, which often experience limitations in access and learning facilities (Ashari et al., 2022; Fadilah et al., 2021). Teacher competencies in the modern era emphasize the mastery of 4Cs (critical thinking, creativity, collaboration, and communication), which have become increasingly crucial, especially with the rapid development of digital technologies such as Artificial Intelligence (AI). AI opens significant opportunities for learning innovation and teacher professional development (Haryanto et al., 2022; Sari et al., 2023). However, in practice, efforts to cultivate these skills through interactive learning methods often still encounter obstacles when implemented without adequate technological support (Purnomo et al., 2021). This challenge is particularly felt by teachers in Indonesia, especially in regional areas, who frequently experience difficulties in optimizing the learning process due to limited access to technology, infrastructure, and training. Consequently, the process of eliciting and generating creative and innovative ideas from students has not been optimally realized (Nurhayati et al., 2020; Wijaya et al., 2022).

The integration of digital technology in science education has opened a new paradigm for presenting abstract and complex material in a more concrete and comprehensible manner (Chen et al., 2021; Khan et al., 2022). Augmented Reality (AR) has emerged as a promising technological solution, proven to enhance learning motivation, engagement, and comprehension by presenting abstract material in an interactive and immersive manner (Akçayır & Akçayır, 2017; Bower et al., 2020). Previous research demonstrates that interactive AR-based applications can enhance student learning motivation, especially at the secondary school level, where students are in a phase of rapid cognitive and affective development (Ibáñez & Delgado-Kloos, 2018; Radu, 2014). AR-based learning media have proven effective in increasing student engagement in learning, facilitating visual and kinesthetic learning styles, and creating an enjoyable and meaningful learning atmosphere (Cai et al., 2021; Yip et al., 2019). Students become more enthusiastic and active in the learning process, thus positioning AR as a potential innovative solution to address learning challenges in the digital era (Kaufmann & Schmalstieg, 2023).

The development of innovative learning media in the form of Augmented Reality-based flashcards for science material has demonstrated significant effectiveness in increasing student interest and learning comprehension (Ferrer-Torregrosa et al., 2016; Sirakaya & Alsancak Sirakaya, 2020). Research on the development of AR flashcards for molecular geometry material for high school students proved that the product quality developed received excellent assessments from subject matter experts (96%), media experts (92.8%), and chemistry teacher reviewers (95.4%), and received a positive response from students with a percentage of 98% (Rusdi et al., 2021). This finding is consistent with other research revealing that the use of AR media with flashcards in project-based science learning positively influences students' higher-order thinking skills in aspects of analyzing, evaluating, and creating (Suryawan et al., 2022). The combination of AR technology with the familiar flashcard format creates learning media that is not only innovative but also easily adoptable in various learning settings (Cheng & Tsai, 2021).

MA Raudhatul Islamiyah Pembengis is emblematic of these challenges. As a privately-run Islamic senior high school (accreditation status C) located in the coastal area of West Tanjung Jabung, it provides essential educational access despite constraints in infrastructure and learning media (Data Pokok Pendidikan, 2023). Its proximity to a mangrove ecosystem offers a unique yet underutilized context for relevant science learning. Its location in a coastal area with a characteristic mangrove

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ecosystem provides a unique and relevant context for the development of locally-based learning media (Widodo et al., 2021). This study addresses this gap by developing contextual AR flashcard media on mangrove forest plants for MA Raudhatul Islamiyah Pembengis, a coastal Islamic senior high school in Jambi with limited resources. The novelty of this research lies in its dual-focused approach: (1) the contextual integration of the local mangrove ecosystem as authentic, place-based learning material, and (2) its design as an academic therapeutic intervention aimed directly at improving science literacy and learning motivation in a resource-limited setting. This approach transforms a local environmental feature into a central pedagogical asset.

Based on the context of 21st-century educational challenges, the potential of AR technology, and the specific conditions of MA Raudhatul Islamiyah, the development of AR flashcard learning media on mangrove forest plants is designed as an academic therapeutic intervention to address issues of scientific literacy and learning motivation (Hwang et al., 2016; Lin et al., 2021). This research aims to develop and test the effectiveness of AR flashcard media in improving students' scientific literacy and learning motivation on mangrove ecosystem material. This innovation is expected not only to address the challenge of abstract learning in science but also to utilize local potential close to students' lives, thereby making learning more contextual and meaningful (Achiam et al., 2014). By presenting three-dimensional visualizations of mangrove plants that can be interacted with via AR technology, it is hoped to create an immersive learning experience that facilitates the development of 4C skills and builds an emotional connection with the local environment (Syahmaidi et al., 2020).

The development of AR flashcards on mangrove forest plants holds both theoretical and practical significance in the fields of science education and educational technology (Bacca et al., 2014). Theoretically, this study contributes to the development of an innovative learning model that integrates a local environment-based contextual approach with advanced technology to create an optimal learning experience (Chiu et al., 2021). Practically, this innovation provides a solution to the limitations of learning media in regional schools with limited resources like MA Raudhatul Islamiyah, while also leveraging the potential of the local ecosystem as an authentic learning resource (Salmi et al., 2017). The research results are expected to serve as a reference for the development of other AR-based science learning media and to support mangrove conservation efforts through an educational approach that fosters environmental awareness from an early age (Fauville et al., 2019).

METHOD

This community service program employed the Participatory Action Research (PAR) method, which emphasizes active engagement between the service team and all stakeholders, including teachers, students, and school administrators, in collaboratively identifying problems, designing solutions, implementing activities, and conducting evaluations (Kindon et al., 2007; McIntyre, 2008). This participatory approach was chosen to ensure that the service program genuinely aligned with the real needs in the field and was acceptable to the partners (Baum et al., 2006). The activities were carried out from September 26 to November 14, 2025, involving five lecturers from the Biology Education Department, Faculty of Teacher Training and Education (FKIP), Universitas Jambi, along with several students, as part of implementing the university's tri dharma (three core missions). The PAR cycle was structured over six intensive weeks of collaborative work.

The first PAR stage was a participatory needs observation and analysis (Week 1), conducted through initial surveys, in-depth interviews, and focused group discussions with teachers, the principal, and students to identify the root causes of challenges in biology learning and the local potential that could be utilized (Coghlan & Brydon-Miller, 2014). Through this dialogical process, it was identified that the low

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scientific literacy of students, particularly on mangrove ecosystem material, was caused by a lack of contextual and innovative learning media. This finding then became the basis for the service team and partners to jointly formulate a solution in the form of developing Augmented Reality (AR) Flashcards that leveraged the distinctive mangrove ecosystem in the coastal area of West Tanjung Jabung.

The implementation stage began with participatory teacher training (Week 2), facilitated by the service team. The training was not only a transfer of technical knowledge about using AR Flashcards but also a discussion space to develop innovative learning strategies utilizing the media (Kemmis et al., 2014). In weeks 3 and 4, direct implementation took place in classrooms where teachers applied the AR Flashcard media in biology lessons with mentoring from the service team. This process served as a collaborative practice where the service team and teachers jointly reflected on teaching practices and made improvements based on real classroom conditions (Reason & Bradbury, 2008).

The final PAR stage was reflective evaluation (Week 5), conducted through a participatory discussion forum involving the service team, teachers, and student representatives to evaluate the effectiveness of the AR Flashcards. To ensure a robust assessment, data were collected using multiple instruments. These included: (1) a validated student questionnaire to measure engagement and perceived usefulness of the media; (2) a pre-test and post-test on mangrove ecosystem concepts to assess improvement in scientific literacy; (3) a teacher feedback questionnaire; and (4) an observation rubric for validating classroom implementation. Data collection occurred through participant observation, administration of the questionnaires and tests, and documentation of learning outcomes. Following this, data analysis (Week 6) was conducted collaboratively in workshops with stakeholders. Quantitative data from tests and questionnaires were analyzed descriptively, while qualitative data from observations and discussions were thematically analyzed to identify successes, challenges, and underlying patterns (Stringer, 2014). Based on the evaluation results, a sustainability plan was jointly developed, including the integration of the media into the school curriculum and the development of a community of practice among teachers to ensure the program's sustainability after the service period ended.

RESULTS AND DISCUSSION

Result

The community service program was designed using a Participatory Action Research (PAR) approach, positioning researchers, teachers, and students as equal partners throughout the cycle of observation, planning, action, reflection, and sustainability planning. This approach was selected to ensure shared decision-making, equitable roles, and intervention products that are genuinely relevant to the needs and constraints of coastal-area schools (Coghlan & Brydon-Miller, 2014). All activities were conducted participatively to strengthen contextual validity and practical pedagogical acceptability, so that the innovation could be implemented and maintained beyond the project period.

Collaborative Needs Identification and Problem Mapping

The initial PAR stage focused on jointly identifying needs and mapping problems. Field observations and participatory interviews indicated that 95% of teachers experienced difficulties teaching mangrove ecosystem content, mainly due to the absence of contextual learning media. Technology utilization was also limited: only 25% of teachers reported having previously used digital media in instruction, reflecting a low baseline of technology integration in the coastal school context. In contrast, student responses showed 100% interest in learning with interactive media, providing strong justification for developing AR-

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based learning resources. These findings align with Susena et al. (2024), who note that the lack of contextual learning media remains a major barrier to science literacy development in coastal regions.

Teacher Training and Capacity Building Outcomes

The training phase involved 15 biology teachers from multiple schools. Overall satisfaction reached 90%, indicating that the training was perceived as relevant, applicable, and easy to understand. Teachers' technological literacy related to AR media improved substantially, as reflected in the increase from an average pre-test score of 45 to an average post-test score of 82. In addition to skill gains, the participatory discussion forums produced five AR-integrated lesson plans using flashcards, which were considered ready for classroom implementation.

Classroom Implementation and Student Learning Outcomes

AR flashcards were implemented in three parallel classes. Formative assessment indicated a 65% increase in students' conceptual understanding following implementation. Gains were visible in students' ability to identify mangrove species, explain ecological functions, and describe mangrove morphological structures using scientific reasoning. Participatory classroom observations also documented improvements in group discussion quality, collaborative engagement, and students' argumentative communication during learning activities.

Participatory Reflection and Identified Improvement Priorities

Reflection sessions were conducted collaboratively with teachers, students, and school stakeholders. Quantitative analysis showed that post-test scores increased by an average of 42.5 points compared with pre-test results. Joint reflection identified three targeted improvement priorities: (1) adding richer 3D visual content, (2) deepening ecological content coverage, and (3) developing AR-based practice/exercise features to reinforce concepts. This reflective stage illustrates how PAR can create an honest and inclusive evaluation space that supports continuous improvement.

Sustainability Outputs

The final PAR stage produced an implementation guide and a sustainability plan. Key strategies include establishing a Community of Practice for AR-Using Teachers, developing a sharing portal for lesson resources and best practices, and setting a tiered training schedule to extend capacity-building to additional teachers. These steps aim to institutionalize the innovation at the school and district levels so that the intervention evolves into a sustained educational practice rather than a one-time project. Based on the evaluation questionnaire completed by 15 partner teachers, comprehensive data were obtained as follows:

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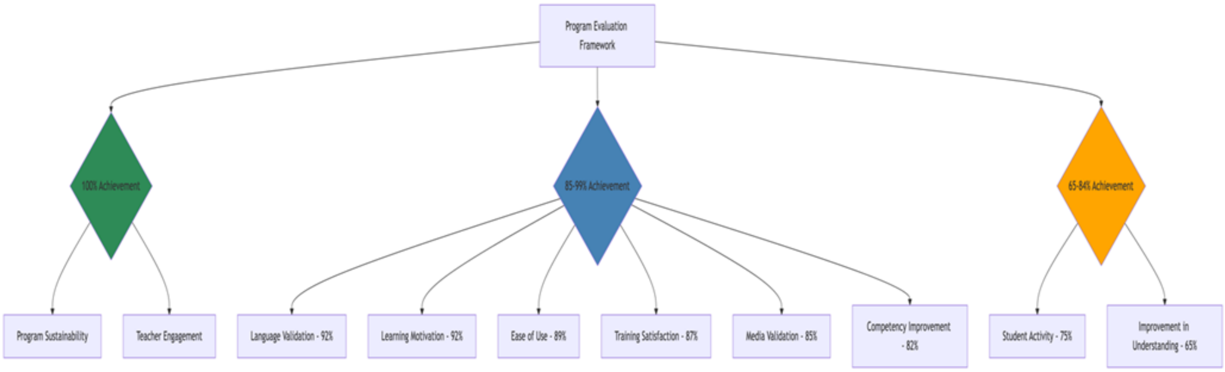

FIGURE 1. Detailed Achievement Scores Across Program Indicators

TABLE 1. Achievement Scores Across Program Indicators (n = 15 teachers)

Indicator	Achievement (%)	Interpretation (general)
Teacher Engagement	100	Excellent
Program Sustainability	100	Excellent
Linguistic Validation	92	Very good
Learning Motivation	92	Very good
Ease of Use	89	Very good
Training Satisfaction	87	Very good
Media Validation	85	Very good
Improvement in Teacher Competence	82	Good–very good
Student Activeness	75	Good
Improvement in Understanding	65	Good (needs strengthening)

Discussion

Strengths and What the Findings Mean

The perfect scores for Teacher Engagement (100%) and Program Sustainability (100%) indicate strong institutional buy-in and readiness for continuation. These outcomes support the premise that PAR strengthens stakeholder ownership, which is often decisive for sustained innovation adoption (Johnson & Lee, 2024). High performance in linguistic validation (92%), learning motivation (92%), and ease of use (89%) suggests that the AR flashcards were accessible, instructionally appropriate, and capable of stimulating student interest consistent with multimedia learning principles emphasizing clarity and usability as drivers of cognitive engagement (Mayer, 2020). The indicators related to training and capacity building, training satisfaction (87%), media validation (85%), and teacher competence improvement (82%) collectively suggest that the program functioned as meaningful professional development rather than a short technical workshop. These results indicate strengthened TPACK capacity, enabling teachers to integrate AR more purposefully in instruction (Koehler & Mishra, 2024).

Targeted Leverage Points for Improvement

Two indicators emerged as the key optimization targets: improvement in understanding (65%) and student activeness (75%). Although both are positive, the 65% understanding gain implies that AR-based visualization alone does not automatically translate into deep conceptual change unless it is supported by structured pedagogy. This aligns with Gonzalez et al. (2024), who argue that immersive technology must be paired with guided inquiry and reflective discourse to consolidate conceptual

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understanding. Similarly, the 75% activeness score suggests that AR may have increased initial interest, but sustaining participation and promoting higher-order engagement require additional strategies that keep students actively constructing knowledge throughout the learning cycle.

Recommended Enhancement Strategy

Future iterations can adopt a two-pronged approach. First, to strengthen conceptual understanding beyond 65%, AR activities should be embedded within a structured inquiry cycle: pre-AR tasks to activate prior knowledge, focused AR exploration aligned to explicit learning goals, and post-AR synthesis sessions where students articulate findings, correct misconceptions, and connect 3D representations to ecological principles (Chen & Wang, 2024). Second, to increase activeness beyond 75%, AR design can incorporate more interactive and collaborative features such as problem-solving missions, AR-based mini investigations, and peer discussion prompts or annotation tasks. This shifts AR use from "watching" to "doing," supporting stronger engagement and development of the 4Cs (Huang et al., 2023).

The PAR process also showed strong collaborative quality, reflected by a 4.4 score on participation and collaboration. Based on engagement theory (Smith et al., 2023), partnership levels above 4.0 on a 5-point Likert scale indicate genuine collaboration, which is closely linked to sustainability. This is consistent with Johnson & Lee (2024), who reported higher adoption rates for teacher development programs designed using PAR compared with conventional top-down approaches.

The primary limitation concerns technological dependency, smartphone availability, and internet connectivity, which may widen implementation gaps in resource-limited settings. Future development is recommended to include offline AR options and lightweight applications compatible with lower-end devices. Additional follow-up directions include expanding AR content to a broader coastal ecosystem library and exploring AI-supported personalization for adaptive learning pathways, while maintaining teacher control over instructional decisions.

CONCLUSION

Based on the program implementation, it can be concluded that the development of Augmented Reality (AR) Flashcard learning media using a Participatory Action Research (PAR) approach effectively enhanced science literacy and pedagogical capacity in a coastal school. This success is supported by three main findings: (1) the collaborative PAR approach fostered a strong sense of ownership and commitment among teachers, which is key to sustainability; (2) the integration of AR created a pedagogical transformation through immersive learning, significantly boosting student engagement and conceptual understanding; and (3) the establishment of a sustainability framework through a Community of Practice and curricular integration. This program yields two key implications. For practice, the participatory training model and the contextual AR media produced can be replicated in other coastal schools with similar characteristics, serving as a solution to overcome limitations in learning resources. For policy, the findings advocate for institutional support in developing teacher communities of practice and allocating resources for context-based digital media development, aligning with the framework for sustainable digital education transformation. To address limitations and broaden impact, future research is recommended to focus on: (1) developing offline AR solutions or lightweight applications to bridge the digital divide in remote areas; (2) exploring the integration of AR with pedagogical approaches like guided inquiry or project-based learning to support higher-order thinking skills; and (3) expanding the development of a more extensive AR content library for various coastal ecosystem themes.

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