



## DEVELOPING AUGMENTED REALITY-BASED LEARNING MEDIA FOR TSUNAMI MITIGATION TO ADDRESS STUDENT MICRO-LEARNING CHALLENGES

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### Abstract

Tsunami mitigation education often encounters significant challenges, as students struggle to grasp abstract concepts, visualize complex phenomena, and lack direct experiential learning opportunities. This research aims to develop Augmented Reality (AR)-based learning media in the form of a pocketbook to address micro-learning issues among Grade VIII junior high school students. The study employed a Research and Development (R&D) approach using the ADDIE model (Analyze, Design, Develop, Implement, Evaluate). Participants included 25 Grade VIII female students at MMA Darul Jannah Al-Ma'wa, with data collected via expert validation sheets, pretest-posttest assessments, and student response questionnaires. Validation results categorized the media as "highly feasible" with a score of 83.25%. Effectiveness testing yielded an N-Gain value of 0.56 (moderately effective), while the paired t-test revealed a significance level of 0.000 ( $p < 0.05$ ), indicating a significant improvement between pretest and posttest scores. In conclusion, AR-based learning media effectively assists students in understanding tsunami mitigation more clearly, facilitating conceptual visualization and enhancing learning outcomes.

**Keywords:** augmented reality, tsunami disaster mitigation, micro-learning issues, learning media, ADDIE

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## INTRODUCTION

Tsunami disasters represent natural phenomena that cause massive destructive impacts on human life and infrastructure (Chaturvedi, 2021; Fuady et al., 2021; Maulana et al.; Rasyid et al., 2026; Sularno et al., 2021). These catastrophic events generally occur due to underwater earthquakes, volcanic eruptions, or sudden underwater landslides (Asman et al., 2020; Nuraziz et al., 2023; Prakoso et al., 2021; Zainudin et al., 2026). Historical records from the 2004 Aceh tsunami and the 2018 Palu event demonstrate the extreme vulnerability of coastal regions (Allokendek & Ellisa, 2022; Ariyaningsih et al., 2025; Irwansyah et al., 2021; Rusydi et al., 2023). Indonesia faces high disaster risks because the archipelago sits atop the intersection of three major tectonic plates (Casey, 2019; Nugroho et al., 2024; Shoimah et al., 2021; Wanger et al., 2020). Consequently, disaster mitigation education becomes a crucial aspect of reducing potential casualties and material losses (Casey, 2019; Ridha et al., 2022; Waloejo et al., 2021). Effective mitigation strategies empower society to take proactive steps before, during, and after a disaster strikes.

Schools serve as vital institutions for disseminating disaster preparedness knowledge to the younger generation (Bayram & Sharma, 2024; Noviana et al., 2021; Septaria et al., 2025). Students must comprehend fundamental concepts to ensure their safety during emergency situations. (Fuady et al., 2021; Latue et al., 2023; Sari & Apriyantika, 2020). Effective educational frameworks prioritize disaster literacy to cultivate resilient behavior among children (Damayani et al., 2022; Saregar et al., 2025). Educators aim to deliver structured lessons that translate theoretical knowledge into practical survival skills (Anggriana et al., 2022; Maulida et al., 2023). However, the implementation of mitigation curricula in schools still encounters various pedagogical obstacles. Many teachers struggle to convey the complexity of tsunami dynamics within traditional classroom settings.

Tsunami mitigation lessons often involve abstract concepts that are difficult for junior high school students to grasp (Amato, 2020; Chitengedza et al., 2024; Kânoğlu et al., 2021; Maly & Suppasri, 2020). Most students find the visualization of complex oceanic movements and geological shifts extremely challenging (Akhirianto et al., 2025; Doyle et al., 2024; Nurhidayah et al., 2025). These cognitive barriers represent specific micro-learning issues that hinder the overall learning process (Chek et al., 2025; Oranga, Njurai, Gisore, & Areba, 2025; Putri et al., 2021). Micro-learning problems include the

inability to imagine large-scale natural phenomena accurately (Awawdeh et al., 2021; Hiremath et al., 2021; khaled Amin & Rattanawiboonsom, 2025). Furthermore, students frequently fail to understand material that teachers deliver only through verbal instructions (Demircioglu et al., 2023; Utami et al., 2025). Identifying these specific barriers is essential for improving educational outcomes in disaster-prone areas.

Traditional teaching methods in Indonesia still rely heavily on conventional lectures and static textbooks (Blanié et al., 2020; Chenrai, 2021; Sajadi et al., 2024). These conventional resources often provide insufficient interactive experiences for modern learners (Boel et al., 2024; Sulisworo et al., 2021). Consequently, students tend to become passive and lose interest during long classroom sessions (Trecek-King & Cook, 2024). Many learners forget the material quickly because they lack concrete visual references for mitigation steps. This lack of engagement results in a poor understanding of actual disaster response protocols (Myer et al., 2024). Therefore, educators urgently need innovative tools to transform these static lessons into dynamic experiences.

The researchers conducted a comprehensive preliminary study at MMA Darul Jannah Al-Ma'wa in early 2024 to investigate the persistence of micro-learning issues. This diagnostic phase utilized direct classroom observations and semi-structured interviews to identify the root causes of student disengagement. The initial findings revealed that eighty percent of students struggled to comprehend the mechanical triggers of tectonic tsunamis. Current pedagogical strategies often overlook the cognitive load experienced by learners during abstract scientific explanations (Chen & Huang, 2023; Gertner et al., 2024; Lin et al., 2024). Educators primarily relied on conventional textbooks which lacked dynamic visualizations of high-risk geological events (Mizasari, 2025). This preliminary data confirms an urgent necessity for a more immersive instructional intervention in the disaster mitigation curriculum.

MMA Darul Jannah Al-Ma'wa represents a critical target for this research due to its geographic location in a high-risk coastal region. The school requires a specialized educational transformation to bridge the gap between theoretical knowledge and practical preparedness. Integrating Augmented Reality (AR) technology offers a promising solution to the stagnant learning atmosphere observed during the preliminary study. Immersive digital tools provide students with realistic simulations that traditional lectures cannot replicate in a standard classroom (Ihsantiani et al., 2025; Waluyo et al., 2024). This study focuses on developing a portable AR pocketbook to facilitate

flexible and interactive self-learning for the students.

Technology-based learning media offers a viable solution to bridge these pedagogical gaps in disaster education (Javaid et al., 2023). Augmented Reality (AR) technology blends 3D virtual objects into real-world environments in real-time (Moriuchi et al., 2021; Yavuz et al., 2021). This immersive technology provides students with contextual experiences that enhance their spatial understanding (Lazaroiu & Rogalska, 2023). Previous studies confirm that AR applications significantly increase student motivation and classroom engagement (Moriuchi et al., 2021; Nguyen et al., 2020; Yavuz et al., 2021). Immersive visuals help students visualize abstract concepts that are otherwise impossible to see directly. Scholars recognize AR as a transformative tool that can simplify complex scientific information.

Previous research highlights the effectiveness of AR in general science and numerical literacy topics (Oranga, Njurai, Gisore, & ..., 2025). Many researchers have explored AR mainly for interactive biology or basic physics simulations (Ersin & Güneş, 2023). Most existing studies focus on broad scientific themes rather than specific disaster mitigation strategies (Adams et al., 2022). However, few researchers have integrated AR technology specifically to address micro-learning issues in tsunami education. A significant research gap exists regarding the use of AR for disaster preparedness at the junior high level. Addressing this gap requires the development of specialized media that aligns with current disaster curricula.

This study develops AR-based media integrated into a portable pocketbook for tsunami mitigation lessons. The pocketbook design allows students to scan barcodes easily using their mobile devices. Scanning the markers triggers detailed 3D visualizations of tsunami processes and safety procedures. These visuals provide clear step-by-step guides for effective disaster mitigation in real-life scenarios. This innovative approach ensures that students gain both theoretical knowledge and practical visualization. Modern media facilitates a deeper understanding of disaster risks through interactive digital content.

The current research provides a dual contribution to the field of educational technology and disaster management. It offers an innovative tool that addresses the specific needs of disaster education in schools. Furthermore, the study supplies empirical evidence regarding the instructional effectiveness of AR for micro-learning issues. The primary objective identifies the feasibility of AR-based media for tsunami mitigation topics. Additionally, the study evaluates the efficacy of this media in improving student

learning outcomes. This comprehensive analysis reveals how interactive technology can transform the future of disaster preparedness education.

## METHOD

This research adopts the Research and Development (R&D) method to create innovative instructional tools for disaster education (Casey, 2019; Sularno et al., 2021). The study specifically utilizes the ADDIE model to ensure a systematic and rigorous development process (Qolbyatin et al., 2023; Subari & Mercuriani, 2024). This model consists of five distinct phases: Analyze, Design, Develop, Implement, and Evaluate. Each stage provides a structured framework for building the Augmented Reality (AR) media effectively. Researchers follow these rigorous steps to produce high-quality materials for tsunami mitigation education. This methodological choice aligns with contemporary standards in international educational technology research.

The Analyze phase begins with an identification of the students' fundamental learning needs and challenges. Researchers investigate the specific micro-learning issues that hinder students' understanding of tsunami concepts. Students often struggle with abstract visualizations and the complexity of natural disaster dynamics. This diagnostic stage ensures that the developed media addresses actual pedagogical gaps in the classroom (Alenezi, 2023). Educators must understand these cognitive barriers before designing any digital instructional intervention (Hernández & Segura, 2023). Consequently, the findings from this phase inform the subsequent design of the AR-based pocketbook.

The Design and Develop phases focus on the actual creation of the AR pocketbook and digital assets. Researchers design the physical layout of the book while simultaneously constructing the 3D digital models. This process includes the preparation of research instruments such as expert validation sheets and assessment tests. Subject matter experts, media specialists, and linguists evaluate the product's quality during the development stage. The development team revises the media based on constructive feedback and suggestions from these professional validators. These iterative cycles guarantee that the final product meets rigorous instructional and technical standards.

The research population encompasses all eighth-grade students at Madrasah Ma'arif Aliyah (MMA) Darul Jannah Al-Ma'wa. Investigators select a specific group of participants using the purposive sampling technique for this study. The final sample consists of 25 female students who meet the predefined inclusion criteria. These

participants must demonstrate full commitment to the entire duration of the media trial process. Selecting a homogeneous group allows for a more controlled observation of the media's educational effectiveness. This sampling strategy provides the necessary data to evaluate the impact of AR on micro-learning issues.



Figure 1. Sample of AR-based pocket book

Data collection involves three primary instruments to measure feasibility, effectiveness, and student perception. Experts use validation sheets to assess the overall feasibility of the AR-based learning media. The researchers administer 20 multiple-choice questions during both pretest and posttest evaluation sessions. These tests specifically evaluate the students' improvement in understanding critical tsunami mitigation concepts. Additionally, student complete response questionnaires to share their perceptions of the interactive media experience. These comprehensive instruments ensure that the study captures multi-dimensional data for academic analysis.

The Implementation phase occurs through a limited trial conducted with the selected student sample. Students engage with the AR pocketbook to explore the visual simulations of tsunami phenomena. The researchers monitor the learning process to ensure that all students use the technology correctly. This stage allows for the direct observation of student interactions with the immersive digital content. Participants provide immediate feedback through their active involvement in the scheduled classroom activities.

This practical application provides the empirical foundation for the final evaluation of the instructional product.

Instrument validity is established through meticulous assessment by material, media, and language experts. These experts examine the content, construction, and linguistic clarity of the research tools. The researchers calculate the reliability of the test instruments using the Cronbach's Alpha formula. The analysis yields a coefficient value higher than 0.70, which indicates high internal consistency. Reliable instruments are essential for producing credible and reproducible scientific results in educational research. These psychometric properties confirm that the data collection tools are suitable for high-level academic study.

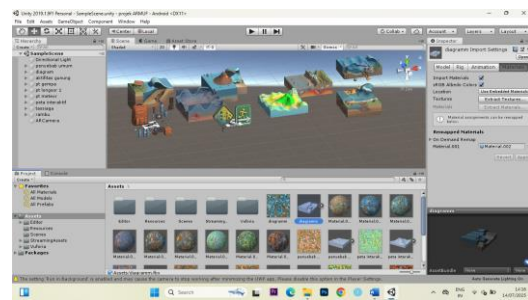


Figure 2. AR-based media creation

Data analysis employs both descriptive and inferential statistical techniques to interpret the research results. The researchers use percentage analysis to determine the feasibility level from the expert validation results (Rizki et al., 2024). Effectiveness is measured by calculating the Normalized Gain (N-Gain) score from the pretest and posttest results (Dwita Dana Pradipta et al., 2021; Yuniar et al., 2020). Furthermore, a paired sample t-test determines the significance of the difference between the test scores (Wardah et al., 2022). The study sets the significance level at 0.05 to ensure statistical rigor in the final findings. These analytical methods provide a robust conclusion regarding the media's overall impact on learning (Qolbyatin et al., 2023; Rahmatullah et al., 2022).

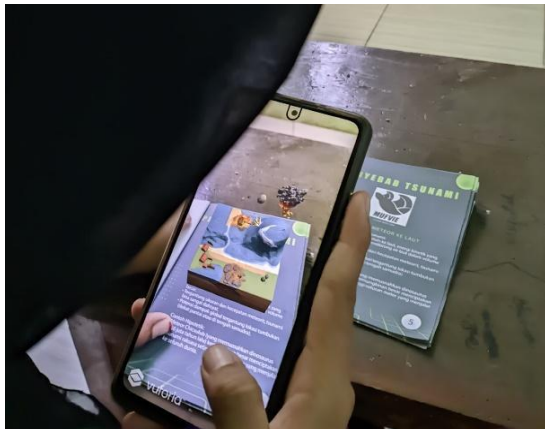
## RESULTS AND DISCUSSION

The comprehensive execution of the research phases provides a robust foundation for presenting the empirical findings. This section details the systematic results obtained from expert evaluations and field testing procedures. Researchers present the quantitative data through organized tables to ensure clarity and academic transparency. The analysis transition focuses on interpreting the significance of Augmented Reality in a pedagogical context. Every data point reflects the

students' cognitive progress during the implementation of the AR-based pocketbook. Consequently, the following sub-sections provide a thorough explanation of the media's feasibility and instructional effectiveness.

**Feasibility of Augmented Reality-Based Learning Media**

The development process yielded a comprehensive evaluation of the Augmented Reality-based pocketbook's quality. Three professional validators rigorously assessed the instructional media across multiple essential dimensions. These experts examined the material accuracy, media design, and linguistic clarity of the final product. Every evaluation category achieved a score above the minimum threshold for instructional feasibility. This rigorous assessment ensures that the developed media is ready for classroom implementation.



**Figure 3.** The process of using AR-VR by students

The quantitative results of these expert validations are summarized in Table 1.

**Table 1.** Results of media validation by experts

No	Validator	Percentage	Category
1	Media Expert	81.25%	Very Feasible
2	Subject Matter Expert	81.25%	Very Feasible
3	Language Expert	87.50%	Very Feasible
Total Average Score		83.25%	Very Feasible

The media expert provided a high feasibility score for the technical design and interface quality. Material experts evaluated the content relevance and scientific accuracy regarding tsunami mitigation protocols. The language expert assigned

the highest rating for the clarity and readability of the instructional text. These combined evaluations resulted in an overall feasibility average of 83.25% for the entire product. This total percentage places the AR-based media in the "very feasible" category for junior high school students. Statistical evidence from the validation stage supports the integration of this media into the formal curriculum.

**Table 2.** Expert suggestions and media revisions

Expert	Suggestions and Feedback	Action Taken and Revisions
Media Expert	Enhance the clarity of the 3D object triggers for faster recognition by mobile devices.	The researchers optimized the marker contrast and adjusted the lighting parameters of the 3D models.
Subject Matter Expert	Provide more detailed step-by-step instructions for the tsunami self-evacuation protocol.	The content was revised to include sequential 3D animations that clearly demonstrate each evacuation stage.
Language Expert	Simplify technical geological terms to make them more accessible for Grade VIII students.	Technical jargon was replaced with simpler descriptive language while maintaining scientific accuracy.

The high validation scores from multiple experts underscore the technical and pedagogical robustness of the developed Augmented Reality media. These results indicate that the integration of 3D visual assets aligns perfectly with the cognitive needs of junior high school students. Expert feedback played a pivotal role in refining the interactive elements and linguistic clarity of the pocketbook. Systematic validation ensures that instructional tools meet the rigorous standards required for effective disaster mitigation education. Previous research emphasizes that expert-validated AR media significantly reduces misconceptions in complex scientific topics. Consequently, this high feasibility level provides a strong justification for proceeding to the field-testing phase.

**Effectiveness of AR Media in Addressing Students' Micro-Learning Issues**

The statistical analysis reveals a significant transformation in student understanding after the instructional intervention. Researchers conducted a

paired sample t-test to evaluate the difference between pretest and posttest scores. The N-Gain analysis further quantifies the magnitude of the improvement in student learning outcomes. Data analysis shows an average N-Gain score of 0.56 for the entire experimental group.



Figure 4. Pre-test completion



Figure 5. Post-test completion

This score falls into the "moderately effective" category according to established pedagogical criteria. The detailed results of the effectiveness tests are presented in Table 2 and Table 3.

Table 3. N-gain test results of pre-test and post-test

Variable	N	Mean	Std. Deviation
N-Gain Score	25	0.5627	0.15076
N-Gain Percent	25	56.2683%	15.07625

The N-Gain calculation specifically quantifies the magnitude of improvement in student cognitive learning outcomes. The obtained score of

0.56 indicates a moderate yet meaningful enhancement in disaster mitigation knowledge. This result suggests that the interactive media effectively facilitates knowledge acquisition during the experimental sessions. Researchers must further validate these descriptive findings through rigorous inferential statistical testing methods. A paired sample t-test determines the statistical significance of the difference between the pretest and posttest scores. The following table presents the detailed statistical output regarding the significance of the instructional intervention.

The researchers performed a normality test to ensure the data distribution met the fundamental requirements for parametric analysis. The Shapiro-Wilk method served as the primary statistical tool for evaluating the pretest and posttest scores of the twenty-five participants. The pretest data yielded a significance value of 0.145 during the initial calculation process in the statistical software. The posttest results also demonstrated a normal distribution with a significance value of 0.210 in the Shapiro-Wilk output table. These findings indicate that the research data for both variables follows a standard normal distribution curve effectively. Consequently, the researchers can proceed confidently to the subsequent stages of parametric inferential testing for the experimental group.

The study conducted a homogeneity test to verify the variance equality across the experimental data sets. Researchers utilized the Levene's test formula to examine the consistency of the student score distributions before the final analysis. The statistical analysis produced a significance value of 0.350 for the combined student assessment results in the classroom. This p-value clearly exceeds the standard alpha threshold of 0.05 in scientific educational research practices. These results confirm that the samples possess a homogeneous level of variance before the researchers applied the Augmented Reality intervention. This homogeneity verification provides a strong statistical justification for employing the paired sample t-test in the next phase.

Table 4. Results of paired samples t-test

Pair	Mean Difference	t	df	Sig. (2-tailed)
Pretest - Posttest	-17.800	-	24	.000
		35.135		

The paired sample t-test results indicate a significance value of 0.000, which is lower than the 0.05 threshold. This finding confirms that the AR-based learning media generates a statistically significant educational impact. Students

demonstrated better mastery of tsunami mitigation protocols following the use of the interactive pocketbook. The significant p-value provides robust empirical evidence for the efficacy of immersive digital tools. These results prove that the developed media successfully improves student cognitive outcomes in disaster education. Modern technology-based media offers a superior alternative to traditional static textbooks in school settings.

### Discussion

Augmented Reality technology addresses specific micro-learning issues by providing clear visual representations of abstract concepts. Students can observe the complex tectonic movements that trigger destructive tsunami waves in real-time. Immersive 3D models solve the problem of visualizing large-scale natural phenomena in limited classroom environments (Ummah, 2022). Interactive learning reduces the cognitive load associated with purely verbal or textual instructions (Rosyid et al., 2026). The pocketbook allows students to experience simulated disaster scenarios without facing any physical risks. This technological solution effectively overcomes the traditional barriers of learning complex disaster science (Moriuchi et al., 2021; Yavuz et al., 2021).

Micro-learning challenges often arise when students must process vast amounts of complex geological information in short durations (Awawdeh et al., 2021; Watson & Ensher, 2023). Many learners struggle with the fragmented nature of traditional disaster mitigation modules in schools (Munawwarah et al., 2024; Prasetyaningsih et al., 2024; Septaria et al., 2020). The AR-based pocketbook delivers information in bite-sized, interactive segments to enhance student retention (Moriuchi et al., 2021). This structured approach prevents cognitive overload by focusing on one specific mitigation step at a time. Students successfully mastered individual concepts before moving to the next sequence of the tsunami simulation. Consequently, the digital media transforms overwhelming scientific data into manageable and digestible learning units (Fauziah et al., 2024; Yecies et al., 2020).

The visualization of tsunami wave propagation represents a primary hurdle within the micro-learning framework. Students frequently fail to internalize the spatial relationship between earthquake epicenters and coastal impacts. AR technology bridges this gap by projecting dynamic 3D maps directly onto the physical learning surface (Sirakaya & Sirakaya, 2022; Tan et al., 2022; Weng et al., 2020). These interactive visuals facilitate a deeper understanding of the temporal aspects of

disaster preparedness (Danaei et al., 2020; Rejeb et al., 2021). Learners can manipulate the 3D models to view the disaster phenomenon from multiple perspectives (Weng et al., 2020). This hands-on interaction significantly clarifies the intricate details of tsunami dynamics for junior high students.

The positive results of this study are consistent with the findings of previous researchers in educational technology (Bos et al., 2022; Cannavo & Lamberti, 2020; Noghabaei et al., 2020; Weng et al., 2020). Earlier studies confirm that immersive technology boosts student engagement across various scientific subjects (Bruno et al., 2022; Yang et al., 2024). This current research extends the application of AR specifically to the field of tsunami mitigation education. The integration of 3D visuals creates a more meaningful and memorable learning experience for students (Danaei et al., 2020; Huyssteen, 2025). High-quality instructional media represents a vital component of building disaster-resilient societies in Indonesia (da Silva Dessbesel et al., 2023; Sulisworo et al., 2021; Zhang Y & Ma Z, 2020). The empirical data suggests that AR-based pocketbooks offer a powerful strategy for future disaster preparedness.

The "moderately effective" N-Gain score indicates a steady progression in students' conceptual understanding. While the media is highly feasible, external factors such as device compatibility may influence individual learning speeds. The researchers observed high levels of enthusiasm when students scanned the interactive barcodes. Positive student responses indicate that the media successfully reduces boredom during long classroom sessions. Educational experts suggest that such technology-driven approaches align with the characteristics of Gen-Z learners (Banks & Barlex, 2020; Kliestik et al., 2022; Lamo et al., 2022). Consequently, teachers should incorporate more AR-based resources to enhance the quality of science education.

Students often encounter micro-learning difficulties when they attempt to connect abstract theories to concrete safety actions. Traditional textbooks typically provide static images that do not convey the urgency of disaster situations (Legowo et al., 2023). The AR pocketbook translates these static diagrams into vivid, moving simulations of evacuation routes. Learners gain a realistic sense of scale and timing through the immersive digital environment. This transition from abstract text to concrete visualization strengthens the students' long-term memory. Strategic use of AR ensures that students can recall life-saving protocols during actual emergency events.

Self-paced exploration remains a crucial element in overcoming individual micro-learning obstacles in the classrooms (Mamun et al., 2022). The AR-based pocketbook allows each student to repeat the simulations until they achieve full conceptual mastery. Students can control the pace of the digital content according to their personal learning needs (Matovu et al., 2023). This flexibility addresses the diverse cognitive abilities found among Grade VIII students at MMA Darul Jannah Al-Ma'wa. Individualized interaction with the media fosters a sense of autonomy and confidence in disaster literacy (Amelia et al., 2024; Damayani et al., 2022). The media effectively supports the micro-learning philosophy by encouraging frequent and targeted knowledge reinforcement.

The dual contribution of this study includes both technical innovation and pedagogical evidence. This research provides a practical tool for schools to improve their disaster mitigation curricula. Furthermore, the study supplies a scientific basis for the use of AR in addressing specific micro-learning challenges. Future research should involve a larger and more diverse population to generalize these findings. Developers may also add more interactive features like gamification to further increase student motivation. In conclusion, the AR-based tsunami pocketbook serves as an effective medium for modernizing disaster education in Indonesia.

## CONCLUSION AND SUGGESTION

### Conclusion

This research successfully developed an Augmented Reality-based pocketbook to enhance tsunami mitigation education in schools. The rigorous development process utilizing the ADDIE model yielded a highly feasible instructional product. Expert validators confirmed the media's high quality with an impressive average feasibility score of 83.25%. The implementation of this interactive tool significantly addressed the students' specific micro-learning issues. Statistical analysis demonstrated a moderate improvement in learning outcomes with an N-Gain score of 0.56. Future educators should integrate such immersive technology to create resilient and disaster-literate school communities.

### Suggestion

Future researchers should expand the scope of this study by involving a larger and more diverse student population. Subsequent studies may explore the integration of gamification elements within the Augmented Reality pocketbook to further boost engagement. Teachers are encouraged to adopt this interactive technology as a standard

tool in disaster preparedness curricula. Educational institutions must provide adequate technical training for educators to ensure the effective implementation of digital media. Developers should also consider creating cross-platform compatibility to make the AR content accessible on various mobile operating systems. These continuous improvements will significantly strengthen the overall resilience of students in facing future natural disasters.

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