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Augmented Reality-Based Learning for Tidal Flood Mitigation in Early Childhood Education: An ADDIE-Based Development Study

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Abstract

Flood disaster preparedness education for early childhood remains a global challenge, especially in coastal communities facing flood threats in North Jakarta. Although the literature acknowledges the need for crisis mitigation education in early childhood, there remains a significant gap in the development of child-friendly, technology-integrated learning media. This study addresses this gap by developing MITBAR (Mitigasi Bencana Banjir Rob), an Augmented reality-based learning medium designed to improve the cognitive abilities and general knowledge of children aged 5 to 6 years. The research employed a research and development approach using the ADDIE model, encompassing needs analysis, instructional design, prototype development, implementation, and evaluation. The developed media integrates an AR mobile application with print-based materials that present comprehensive content on definitions, causal factors, impacts, and stages of disaster mitigation. Expert validation demonstrated high effectiveness across material experts (N Gain = 1.0), technology experts (0.96), language experts (0.92), and educator practitioners (0.91 to 0.87). Field testing conducted in a kindergarten in North Jakarta, involving five children in a small-group trial and sixteen children in a larger implementation stage, showed substantial improvements in conceptual understanding, with N-Gain values exceeding 0.79 and categorized as highly effective. These findings indicate that Augmented Reality can effectively transform abstract disaster preparedness concepts into experiential learning appropriate for early childhood contexts. Beyond the local setting, this study contributes to broader debates on immersive technology in early childhood disaster education by offering a developmentally grounded, systematically validated AR-based instructional model applicable to flood-prone coastal regions globally. However, the study is limited by its small sample size and short-term evaluation period, and it focuses primarily on cognitive outcomes. Future research is recommended to employ longitudinal designs and examine affective, behavioral, and long-term preparedness outcomes.

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Introduction

Indonesia, as an archipelagic country comprising approximately 17,408 islands, faces significant challenges in disaster management, aligning with UNESCO's Disaster Risk Reduction (DRR) Education framework and the national priority of strengthening community resilience through the Pancasila Student Profile. Data from the National Disaster Management Agency indicate that floods are the most frequent type of disaster, with 11,679 recorded incidents between 2009 and June 2023, while tidal flooding caused by sea level fluctuations remains a recurring threat in coastal areas such as the Penjaringan District of North Jakarta (Suci Hendrawati & Sulandari, 2023; Yoani et al., 2023). The frequency and intensity of tidal flooding are projected to increase due to multiple interacting factors, including sea-level rise, global warming, land subsidence, and broader climate change (Azizah et al., 2024; Chairani et al., 2024; Hadinata et al., 2022).

Tidal flooding will impact people's lives; its impact extends beyond physical damage to infrastructure to include complex social, economic, and psychological consequences (Diana et al., 2024; Nurdiantoro & Arsandrie, 2020). Early childhood is the most vulnerable group facing immediate physical threats and long-term psychological effects, including post-traumatic stress disorder (PTSD), even from exposure to a single disaster (Amelia & Fitriyani, 2023; Yuliana et al., 2022).

Considering that the age of 5-6 years is a critical period in the formation of school readiness, especially the dimensions of cognition and general knowledge which include environmental understanding, spatial reasoning, scientific thinking skills, and problem solving (High et al., 2008; National Education Goals Panel, Washington, 1995; Ricciardi et al., 2021), the integration of disaster mitigation education is essential not only for physical safety, but also to strengthen children's cognitive capacity in understanding complex environmental systems, developing procedural thinking (mitigation stage), and building risk anticipation skills which are the basis of scientific literacy and academic readiness.

Initial observations at an Early Childhood Education institution in North Jakarta revealed a critical issue: children aged 5-6 years demonstrated minimal understanding of tidal flooding, including its causes, potential impacts, and appropriate mitigation responses across the pre-disaster, emergency response, and post-disaster phases. This lack of knowledge stems from limited educational resources, methodologies, and conventional one-way teaching, as well as educators' concerns about delivering disaster content appropriate to children's cognitive development (Nindiawati et al., 2021; Nurfadilah & Darsono, 2021). Although UNESCO emphasizes early disaster risk reduction (DRR) education, and Indonesia integrates disaster preparedness into the Pancasila Student Profile curriculum (Furqan et al., 2021), pedagogically appropriate, technology-supported disaster education materials for early childhood remain scarce.

A recent literature review (2018-2024) identified three studies that have not been optimally integrated. First, *augmented reality* (AR) technology has demonstrated significant effectiveness in early childhood education for science, literacy, and numeracy, with engagement increasing by 78-86% compared to conventional methods. (Abidin & Haq, 2023; Baiti et al., 2024; Destiawati et al., 2024; Ningrum & Nur, 2023; Telussa et al., 2023) . Theoretically, AR uniquely overcomes the limitations of Piaget's preoperational stage, where children aged 5-6 years have difficulty with abstract mental representations by transforming the concept of 'a robbing flood' from abstract to explorable 3D manipulatives (rotation, zoom), AR provides a cognitive bridge from preoperational thinking to concrete causality understanding (Istiqomah & Maemonah, 2021; Saputra et al., 2023).

In Vygotsky's framework, AR functions as a digital 'More Knowledgeable Other' (MKO) that provides an adaptive framework in the form of audio narratives and visual cues that guide children in their Zone of Proximal Development without relying entirely on teacher mediation (Suardipa, 2020). This approach is also consistent with Bruner's constructivism, which emphasizes active knowledge construction through direct experience (Murdy & Wilyanita, 2023). Ida Wahyu Wijayati (2024) showed that across 25 articles from the Google Scholar, Scopus, ERIC, Garuda, and DOAJ databases for the period 2019-2024, AR media improved learning outcomes, with an effect size of d = 0.68.

Both studies on disaster mitigation education for children demonstrated the effectiveness of experiential-based approaches through big books (Agrestin & Maulidiyah, 2021) and games (Anindhita et al., 2024). However, the majority focused on earthquakes and fires, with minimal research on tidal flooding, a specific coastal phenomenon that requires a unique understanding of tidal dynamics (Dwi Jayanti Kurnia Dewi, 2022). The limitations of non-digital approaches (big books, physical games) lie in: (1) static representations that cannot model the temporal dynamics of tidal flooding (tidal cycles), (2) the absence of interactive simulations for making evacuation decisions in real-time, and (3) the lack of multisensory engagement (visual-auditory-kinesthetic) which is crucial for early childhood memory retention.

Third, there has been no systematic research linking AR technology, tidal flood mitigation education, and early childhood cognitive development within a school preparation framework, even though both fields (disaster education and AR) are developing concurrently. However, three fundamentally interrelated gaps remain.

Methodologically, most Augmented Reality research in early childhood relies on quasi-experimental designs and fails to document the stages of product development systematically. The use of instructional design frameworks such as ADDIE, which integrate expert validation, practitioner input, and field testing, remains limited in the development of technology-based disaster education for early childhood. As a result, the quality, feasibility, and developmental appropriateness of educational products are often insufficiently verified prior to implementation. In addition, existing studies rarely examine how AR can be adapted to address the complexity of disaster mitigation concepts, including multifactorial causality, multidimensional impacts, and multi-step procedures. Instead of adopting a holistic multidomain approach that integrates cognitive, safety, and socioemotional dimensions, most AR applications for young children focus on single-domain content such as science or literacy.

From a contextual perspective, international literature on disaster education is dominated by studies on tsunamis and earthquakes, with limited attention to tidal flooding as a distinct coastal phenomenon with unique hydrodynamic and temporal characteristics. This imbalance has led to a scarcity of validated, culturally relevant disaster education resources for Indonesian coastal communities. These gaps raise a fundamental research question: how can reality-based learning materials be systematically designed to enhance young children's cognitive capacities while simultaneously fostering practical preparedness for tidal flooding? Effective preparedness behavior is grounded in cognitive development, particularly understanding causal relationships, procedural reasoning, and risk anticipation. Children who conceptually understand why tidal flooding occurs are, therefore, better equipped to predict disaster timing and respond appropriately than those who rely solely on rote procedural instruction.

To answer these questions, this study aims to develop and evaluate integrated Augmented Reality-based MITBAR (Mitigasi Bencana Banjir Rob) learning media: (1) Improve cognitive abilities and general knowledge of 5-6 year old children about flood disaster mitigation as a component of the academic dimension of school readiness; (2) present comprehensive content (pre-disaster, emergency response, post-disaster) in a format that is appropriate to Piaget's pre-operational stage with Vygotskian scaffolding; and (3) demonstrate validity, practicality, and effectiveness through systematic expert validation (content, technology, language, practitioners) and multilevel field testing (small-large groups).

This study makes both theoretical and practical contributions. Theoretically, it demonstrates how immersive technologies can be systematically designed for early childhood education by integrating educational technology, child development, and disaster risk reduction. It introduces the concept of a Technology Mediated Zone of Competence, extending Vygotsky's Zone of Proximal Development through multimodal Augmented Reality learning. Practically, the study offers a replicable model for disaster risk reduction education in vulnerable coastal communities at the early childhood level. It also shows that disaster education can be integrated with academic learning rather than treated as a separate safety-oriented domain.

Methods

Research Design

This study adopted a Research and Development (R&D) design employing the ADDIE instructional model to systematically develop and evaluate Augmented Reality-based learning media for early childhood disaster mitigation. The selection of ADDIE was analytically grounded in its capacity to integrate formative evaluation within each development phase, allowing iterative refinement based on empirical feedback rather than post hoc assessment alone. Unlike linear development models, ADDIE offers methodological flexibility that is particularly relevant for early childhood contexts, where cognitive readiness, usability, and ethical considerations must be continuously reassessed (Junior, 2023; Martatiyana et al., 2023). The study did not position learning effectiveness testing as a causal experiment, but rather as a developmental evaluation intended to assess instructional feasibility and functional effectiveness of the product. Consequently, analytical emphasis was placed on product quality improvement and learning-gain trends rather than on hypothesis testing or statistical generalization.

Research Setting and Duration

This research was conducted over eight months, from November 2024 to June 2025, in two Early Childhood Education institutions located in coastal North Jakarta, Indonesia. The study sites included PAUD Permata UHAMKA, used for small-group testing, and TK Aisyiyah Bustanul Athfal 86, which served as the large-group implementation site. These institutions were selected because they are situated in coastal areas that are periodically affected by tidal flooding, making them contextually relevant to the disaster mitigation content developed in this study. Using two different institutions allowed the implementation of the learning media in distinct classroom settings, enabling assessment of its applicability across varying group sizes. This site selection supports ecological validity by ensuring that the learning intervention aligns with the environmental risks experienced by the participating children.

.Development Procedures

The development procedure follows the five ADDIE stages as follows:

Phase 1: Analysis (November-December 2024)

Observations at three Early Childhood Education institutions in Muara Angke and interviews with 5 educators. About disaster education practices, obstacles, and media needs. Findings: (1) Children's knowledge about tidal floods is limited, (2) learning relies on books without digital media, (3) 78% of children have smartphones at home. AR is effective for children aged 5-6 years because it transforms abstract concepts into tangible 3D visualizations (Baiti et al., 2024). The identified content is 19 sub-topics: basic concepts (2), natural factors (4), anthropogenic factors (5), impacts (5), and mitigation (3).

Phase 2: Design (January-February 2025)

Storyboard: Developed 19 interactive menus, including: menus 1-2 (Definition of tidal flood, coastal ecosystem), menus 3-6 (natural causes), menus 7-11 (anthropogenic causes), menus 12-16 (Impacts), and menus 17-19 (Mitigation). Interface design: Large visual icons, bright colors, simple navigation for pre-literate children.

Phase 3: Development (March-April 2025)

Products: 1. AR Application: 19 menus with rotatable/zoomable 3D objects, emergency bag preparation mini game (feedback ✓ / ✗), and background music. Print Book: 19 AR markers; double as scanning media and a teacher review tool. Tools: Unity 3D, Vuforia (AR tracking), Adobe Illustrator (graphic design).

Phase 4: Implementation (May-June 2025)

Table 1. Expert Validation Qualifications

Validator	Qualification
Early Childhood Education Material Expert (n=1)	Master of Science in Early Childhood Education
AR Technology Expert (n=1)	Master of Educational Technology/Informatics
Linguist (n=1)	Master of Indonesian Language Education
Teacher Practitioners (n=2)	S1 PAUD, Principal/senior teacher

Instrument: 45-item questionnaire (4 dimensions), Likert Scale 1-4. Reliability: Cronbach's Alpha = 0.87; Content Validity Index (CVI) = 0.89. Field Test (n = 21 children), Small Group (n = 5) = PAUD Permata UHAMKA, and Large Group (n = 16) = TK Aisyiyah Bustanul Athfal 86. For the criteria: children aged 5.0-11 years, attendance > 80%, not diagnosed with cognitive/sensory disorders, accustomed to touchscreens, parental consent + child consent. Ethical Permit ECE - 2024-001 (January 15, 2024); anonymous data; accompanying teacher; right to resign at any time.

The instruments used with children include: Pre-test: 20-item pictorial questionnaire; Post-test: 20-item parallel form (3-5 days after intervention); and the scale used is derived from STPPA Permendikbud 137/2014.

Table 2. A list of questions for the evaluation of 5-6-year-old children

Answer	Score
Backward Stage (BB)	1
Beginning to Development Stage (MB)	2
Develop as expected (BSH)	3
Significantly well developed (BSB),	4

Protocol: (1) Pre-test, (2) Intervention, (3) Post-test, (4) Engagement observation.

Phase 5: Evaluation (July 2025)

The evaluation phase was conducted to measure the media's feasibility through expert validation and learning effectiveness through pre-test and post-test analysis. Data analysis used the N-Gain formula for both aspects. The evaluation also utilized data triangulation from three perspectives: source triangulation, method triangulation, and theoretical triangulation.

Table 3. Tafsir (Astuti Salim & Vrita Tri Aryuni, 2022)

N-Gain	Category	Interpretation
>0.7	Tall	Very Effective
0.3-0.69	At the moment	Quite Effective
<0.3	Low	Less Effective
N-Gain	**Category**	**Interpretation**

Research Subjects and Validators

The research subjects were 21 children aged 5 to 6 years, selected through purposive sampling to ensure alignment with the learning media's developmental objectives. Inclusion criteria were applied to control learning exposure and cognitive readiness, including attendance above 80 percent, absence of diagnosed cognitive or sensory impairments, familiarity with touchscreen devices, and documented informed consent. These criteria were implemented to minimize confounding factors that could influence learning progression outcomes. Children served as the primary unit of analysis for evaluating learning effectiveness within a developmental evaluation framework. Media feasibility was assessed by five validators comprising experts holding master's degrees (S2) in relevant academic fields and two teacher practitioners holding bachelor's degrees (S1) who served as principals or senior teachers, thereby ensuring that validation integrated both academic rigor and practical classroom experience.

Research Instruments

Research instruments were designed to support both media feasibility evaluation and learning effectiveness assessment. Expert validation employed a structured questionnaire using a four (4) point Likert scale to assess technological quality, pedagogical suitability, content relevance, and language appropriateness, ensuring decisive expert judgment. Child learning assessment instruments consisted of a pictorial pretest and a parallel posttest administered by classroom teachers, consistent with early childhood assessment principles. Indicators were adapted from STPPA Permendikbud 137 Tahun 2014 to maintain curricular alignment while contextualizing disaster mitigation content. These instruments were analytically positioned as performance-based assessments rather than conventional cognitive tests.

Data collection technique

Data were collected using multiple complementary techniques to capture diverse dimensions of media performance. Expert validation was conducted in two iterative rounds, before and after product revision, to ensure that revisions were empirically informed. Pre-test and post-test assessments were administered to identify learning progression following exposure to the media. Classroom observations were conducted to document engagement, interaction patterns, and usability issues not captured by test scores. The integration of these techniques strengthened methodological rigor by cross-verifying data sources.

Data Analysis Techniques

Media eligibility was evaluated by expert validation using the N-Gain formula, calculated as the ratio of the score obtained to the maximum possible score (N-Gain = score obtained / maximum score). This analysis was applied to determine the extent to which the developed media met predefined feasibility criteria. Learning effectiveness was assessed using pre-test and post-test data and analyzed with the normalized gain formula (N-Gain = (Spost − Spre) / (Smax − Spre)), which measures proportional learning progression relative to initial performance. N-Gain values were interpreted using standardized categories: scores greater than 0.7 indicate efficient outcomes, scores between 0.3 and 0.69 indicate quite effective outcomes, and scores below 0.3 indicate less effective outcomes.

Data credibility was strengthened through triangulation procedures encompassing source triangulation by comparing assessments across four validator groups, method triangulation through integration of quantitative scores with qualitative expert comments and engagement observations, and theoretical triangulation by interpreting findings using Piaget's cognitive development theory and Vygotsky's sociocultural framework.

Result

Analysis

The analysis stage is a planning step that identifies the need for learning media appropriate to the characteristics of early childhood (Anggraini et al., 2021; Novia et al., 2023). Based on observations and interviews with PAUD institutions in Muara Angke, North Jakarta, he shows that children's knowledge of flood disaster mitigation is minimal. This can be interpreted as meaning that learning methods in PAUD are still less modern. Learning methods at PAUD Muara Angke still rely heavily on textbooks and lack adequate media support, thereby reducing children's engagement. In fact, when learning activities are integrated with technology, they can increase children's interest and learning effectiveness. Given that smartphones have become a popular and accessible technology for various groups, researchers are developing technology-based learning media. Literature research shows that *Augmented Learning is a powerful tool. Reality* (AR) is the method that is ideal for providing Interesting and interactive education for children aged 5-6 years (Baiti et al., 2024)

AR learning media is dedicated to providing up-to-date flood disaster mitigation materials, including precaution, mitigation, readiness, response, and recovery. This material is adapted to young children's level of understanding. AR technology transforms abstract ideas into tangible visualizations, thereby increasing children's understanding and engagement in learning.

Design

The follow-up to that analysis is being designed, and the researchers will design *Enhanced Reality* – learning (Wulandari & Hendriana, 2021). The *researcher's storyboard design enriches learning. Reality application design.* This design includes a draft of the content from material obtained from several sources, a selection of 5, and a determination of the form to be used in the Say application. That beginning step is to make A rough outline for *an augmented reality application* containing the following materials:

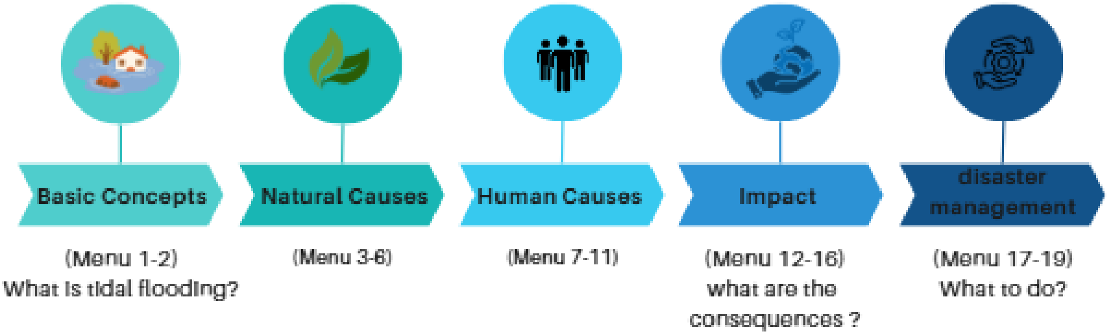

Figure 1. Conceptual Learning Flow

Table 4. Cognitive Contribution of Each Phase

Phase	Cognitive Competence	Order of Who
Phase 1: Basic Concepts	Introduction and Understanding of Phenomena	Knowledge Base
Phase 2: Natural Causes	Environmental factor analysis	Understanding natural cause and effect
Phase 3: Human causes	Awareness of human role	Understanding responsibility
Phase 4: Impact	Multidimensional consequence evaluation	Risk awareness
Phase 5: Disaster Management	Application of mitigation measures	Practical awareness

This curriculum was developed using studies on tidal flood mitigation and media development theories in early childhood education. After the application form, which explains the concepts/materials, was created, the next stage was application development.

Development

At this development stage, he is a continuation of the storyboard design stage that has been designed (Waruwu, 2024). The next step is the process of creating *Augmented Reality-based learning media devices* and the MITBAR (Tidal Flood Disaster Mitigation) book.

Figure 2. Front Cover See from That Application

In That First picture, You Can see that the initial cover displays the application Name MITBAR (flood robbery mitigation).

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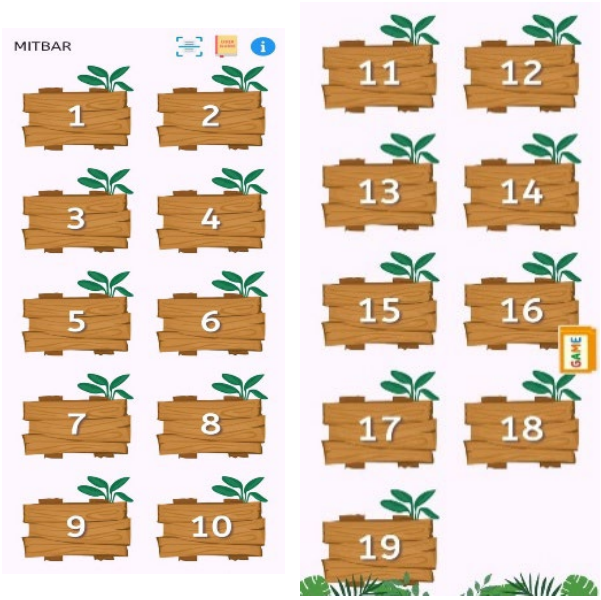

Figure 3. Beginning Opening Menu Showing

In this section, numbers 1 to 19 contain material according to *the storyboard* created at the design stage. The image of number 3, located in the middle of the display in the material 1 menu, is a 3-dimensional design that will be displayed to early childhood, as shown in this picture, which explains Coastal ecosystems. Furthermore, this 3D image can be rotated and zoomed in or out.

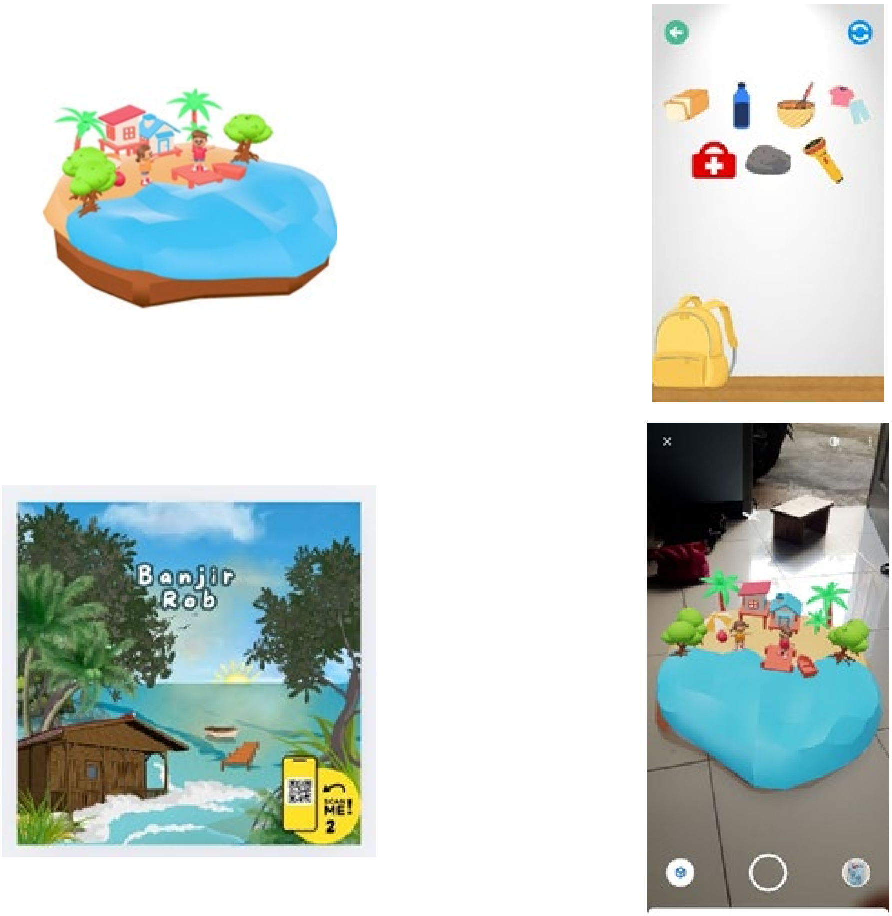

Figure 4. AR views and menus

Number 3 shows an integrated AR 3D view, a game menu in the MITBAR application, and a book for scanning barcodes. This 3D model appears in real-time or is seen in the real world. This AR can interact with Physical environments, such as floor surfaces. Objects here can be rotated, scaled, or moved. Users can view these 3D objects on AR-enabled devices. This section displays a cross to go back, a square menu to view only 3D, and a circle. In the middle, document AR. Moreover, finally, the far right is the result of AR Documentation. This is the game menu in the MITBAR app. The game features music, *a return signal,* game replay, and equipment to prepare before a disaster strikes. And another bothersome object. This game is played by placing objects on the table. When the object is correctly picked, a check mark will appear; if it is incorrect, a cross will appear. Besides being a place to scan barcodes, this book can be used by teachers *to review* material covered in the MITBAR application. It can also help develop reading skills and general knowledge in children aged 5-6.

Implementation

After that, the learning media have developed very well. The next stage is to conduct validation and testing with children aged 5-6 years (Sungkono et al., 2022). Before being tested on children, What needs to be done is to conduct a skills test first by providing assessment instruments such as As a language instrument for linguists, a technology instrument for technology experts, a material instrument for PAUD experts, educators will be given a questionnaire for teacher assessment and a questionnaire for child assessment to see whether this media can improve cognition and general knowledge. If on that validator stage, those trials produce A Good response. Then, this MITBAR, the product can be said to be suitable for use.

Next, if the questionnaire for experts and teachers is ready, then each component will be provided. In the assessment, the final results will be based on the N-Gain score criteria. The results obtained by each validator can be explained in the learning media feasibility test results table below:

Table 5. Benefits of N Interpretation Criteria

Benefits of N Reach G	Category	Interpretation
I 0.7	Tall	Very Effective
0.3 I G < 0.7	At the moment	Reasonable Effective
G < 0.3	Low	Less Effective

The interpretation criteria for the final evaluation are based on the Benefits of the N assessment. There are 3 categories: tall (G I 0.7), at the moment (0.3 I G < 0.7), and low (G < 0.3).

The results of the expert test determine whether the learning media is suitable or not for use by using the following assessment score results:

Table 6. Test of that possibility from the learning media

Respondents	Presentation	Information
Material Expert	1	Very Effective
Technology	0.96	Very Effective
Linguist	0.92	Very Effective
Laboratory School Teacher from Gemstones UHAMKA Early Childhood Education Programs	0.91	Very Effective
Kindergarten Teacher Aisyiyah Bustanul Athfal 86	0.87	Very Effective

The results from the small-group trials held at the Laboratory School, Early Childhood Education Programs, Gemstones UHAMKA, specifically for children in group B aged 5-6 years, with a total of 5 students in the small group. In the small group test, the results obtained are as follows:

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Table 7. Results from the small group test

No.	Name	Sign
1.	AMR	0.7191
2.	ARN	0.7174
3.	DVN	0.7
4.	MHz	0.6703
5.	Sergeant	0.6966
	Amount	**3.5035**
	Average	**0.7007**
	Media Category	**Very Effective**

The results from the big-group trials are held at Kindergarten Aisyiyah Bustanul Athfal 86, which is Kindergarten B, for children aged 5-6 years old, with a total of 16 students. In the large group trial, the results obtained are listed in the following table:

Table 8. Results from the small group test

No.	Name	Sign
1.	AJN	0.5132
2.	ARK	0.6543
3.	II	1
4.	ASH	0.9024
5.	ATN	0.72
6.	ARM	0.7067
7.	SM	0.7368
8.	CH	0.8219
3 9	GBN	0.8028
10.	HDL	0.6176
11.	HNH	0.6974
12.	KZE	0.725
13.	MLQ	0.6522
14.	ZY	0.6471
15.	KM	0.6395
16.	SH	0.5682
	Amount	**11,405**
	Average	**0.7128**
	Media Category	**Very Effective**

Evaluation

After the learning media product is implemented, the final step is to conduct an evaluation. This process aims to assess the validity and suitability of the product and to identify the positive and negative aspects of the learning media created (Iskandar & Mayarni, 2022). Data and information obtained from learning media products are used as a basis for assessment and improving the media based on the suggestions gathered. Weaknesses in the product's learning media will be improved and adjusted until they reach the required quality standards. For high-quality learning media products, consult recommendations from experts in the field.

The input used as evaluation material in this study was derived from several expert and practitioner validators. *First*, feedback from the technology expert indicated that the media was categorized as quite effective in terms of interactivity. However, the validator noted that children's active participation was still limited because the Augmented Reality features did not sufficiently encourage exploratory engagement. Some interactions were perceived as passive, reducing opportunities for child-initiated action. To address this limitation, the validator recommended enhancing interactivity by enabling three-dimensional objects to move or respond dynamically to children's actions. This improvement was considered necessary to strengthen experiential learning.

Second, feedback from the language expert showed that language comprehension aspects were generally rated as quite effective and largely appropriate for children's developmental level.

The language used was considered understandable and accessible for early childhood learners. Nevertheless, the validator identified several terms that lacked consistency in usage across the media. It was therefore recommended that terminology be refined and standardized to ensure clearer and more precise alignment with children's linguistic abilities. This revision was intended to improve clarity and maintain consistency throughout the learning materials.

Third, feedback from the teacher at the PAUD Permata UHAMKA Laboratory School indicated that the content and material presentation were rated quite effective. However, some concepts were perceived as overly complex for children aged five to six years. This level of conceptual complexity was considered to reduce assessment effectiveness and hinder comprehension. The validator suggested incorporating simpler and more concrete learning activities to support children's understanding. Practical, experience-based additions were recommended to facilitate gradual concept acquisition in line with early childhood cognitive development.

Fourth, feedback from the teacher at TK Aisyiyah Bustanul Athfal 86 revealed that the suitability of content and presentation was also rated as quite effective. This assessment was influenced by the substantial media coverage of the causes and impacts of tidal flooding. The validator suggested limiting content to at least 3 key points per learning dimension to avoid cognitive overload. In addition, the evaluation component was considered limited because it primarily focused on conceptual memorization. It was therefore recommended that assessment be expanded to include broader developmental domains, such as religious and moral values, motor skills, cognitive development, language, social-emotional development, and art, in accordance with early childhood education assessment principles.

Discussion

The convergence of expert validation results for subject matter (N-Gain = 1.0), technology (N-Gain = 0.96), and language (N-Gain = 0.92) reveals a fundamental principle: Pedagogical effectiveness is the learning power resulting from the synergistic interaction of all dimensions, not simply the sum of the attributes of each component. This finding dispels the assumption that improving a single factor, such as technological sophistication, will automatically lead to better learning. Instead, a comprehensive learning ecosystem has been successfully created through the systemic alignment of language that adapts to the Zone of Proximal Development (ZPD), content that is progressively organized from the concrete to the abstract, and technology that bridges cognitive transitions (Salsabila & Muqowim, 2024).

In MITBAR, Augmented Reality (AR) technology serves as an instrument for operationalizing Vygotsky's knowledge construction, not merely a digital decoration. AR transforms abstract instructions regarding evacuation and mitigation into a concrete visual-spatial experience within the child's physical space. However, when the language dimension is not aligned with Piaget's preoperational stage, cognitive overload will still occur, regardless of the technology used (Istiqomah & Maemonah, 2021).

A thorough understanding of the cognitive characteristics of Piaget's pre-operational stage is crucial to MITBAR's success in improving children's understanding (N-Gain for small group = 0.7007; large group = 0.7128) (Sinaga & Choiriyah, 2023). Children aged five to six years are undergoing a crucial shift from sensorimotor thinking, which relies on manipulating real objects, to symbolic thinking, which allows for mental representation (Istiqomah & Maemonah, 2021).

Children at this stage still have minimal verbal abstraction abilities, creating an educational paradox: learners who are not yet able to think abstractly must understand disaster mitigation concepts that are inherently abstract, such as cause-and-effect relationships, counterfactual scenarios, and temporal projections. In this situation, AR offers a cutting-edge pedagogical approach by creating a transitional space through a virtual concretization process that bridges the gap between the real world and abstract understanding (Destiawati et al., 2024).

Children viewing virtual flood visualizations on the classroom floor are not simply watching passive 2D animations. Instead, they are engaged in a semi-concrete simulation that allows for manipulating variables impossible in the real world, such as accelerating water flow or changing

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the flood level, while still experiencing the spatial and temporal dimensions of the physical experience (Uno, 2024). Bruner categorizes this process as an enactive-iconic-symbolic learning transition; children actively interact through AR (enactive), form clear mental images (iconic), and ultimately develop a deeper understanding of the mitigation concept (symbolic) (Afidati & Nur Malasari, 2023).

There are important scientific and practical implications for the consistency of MITBAR's effectiveness across trials (Atikah et al., 2023). Methodologically, the stability of these results indicates that MITBAR has high reliability and does not depend on ideal teacher-student ratios or tightly controlled learning environments—qualities rarely found in educational innovations that often only succeed in experimental settings. In practice, these findings confirm the potential scalability of MITBAR for implementation in early childhood education (PAUD) throughout Indonesia, which still faces systemic challenges such as limited teacher numbers and varying infrastructure (Telussa et al., 2023).

Structural barriers that often hinder innovation adoption in resource-limited environments were successfully overcome by MITBAR, which has proven capable of maintaining learning quality in both small and large groups. This consistency demonstrates that MITBAR's design has integrated the principles of self-directed learning, resulting in individual exploration and differentiated learning. This is because children's interactions with AR content are no longer entirely dependent on intensive teacher guidance (Abidin & Haq, 2023). This finding aligns with UNESCO's vision of disaster risk reduction education that is inclusive, widely accessible, and not limited to schools with luxurious facilities (Furqan Ishak Aksa et al., 2021).

Unlike traditional approaches, the MITBAR dual-modality component of a physical book as a marker and AR digital content successfully operationalizes Kolb's Experiential Learning Cycle (Marlina et al., 2025). Through the printed book, children construct abstract conceptualizations of mitigation principles through illustrations. Next, children engage in concrete experiences when the digital device projects a flood simulation into their physical space. This cycle is reinforced through active experimentation, where children engage in educational games that mimic emergency responses in response to visual triggers from the book (Anindhita et al., 2024).

MITBAR facilitates these four phases in a flexible, iterative cycle, allowing children to transition between phases at their own cognitive pace. Through activities involving various visual (AR animation), haptic (physical book interaction), auditory (narration), and kinesthetic (AR perspective movement) coding pathways, this combination of print and digital media ensures multisensory stimulation for early childhood. The activity of these pathways neurologically strengthens the formation and consolidation of long-term memory (Ningrum & Nur, 2023). Cognitive neuroscience studies confirm that multimodal learning produces stronger and more easily recalled memory traces than unimodal learning, because information is encoded through mutually reinforcing representational systems (Heni Jusuf, 2023).

The effectiveness of MITBAR challenges the paradigm of early childhood disaster education in Indonesia, which has prioritized the dissemination of factual information and evacuation drills without fostering in-depth conceptual understanding (Nurfadilah & Darsono, 2021). This study demonstrates that, through technology aligned with cognitive developmental characteristics, children aged 5 to 6 years can grasp complex concepts. This understanding encompasses the causal relationship between anthropogenic factors (such as coastal environmental damage) and natural disasters, the multidimensional impacts of disasters (physical, social, economic, and psychological), and proactive mitigation strategies that go beyond mere reactive responses (Dwi Jayanti Kurnia Dewi, 2022).

These findings underscore the need to transform the curriculum from a purely disaster-drill model to a comprehensive disaster literacy model. In this model, physical evacuation drills are maintained alongside cognitive (conceptual understanding) and affective (risk awareness without excessive anxiety) dimensions (Efastri et al., 2023). The integration of Augmented Reality technology at MITBAR helps demonstrate access to high-quality disaster simulations. Children in areas where it is geographically difficult to simulate real tidal floods now acquire this literacy through virtual simulations (Agrestin & Maulidiyah, 2021). Furthermore, interaction with multimodal information in MITBAR helps build digital literacy, an essential competency that equips children to face the 21st-century educational and professional ecosystem (Anang Fathoni, 2023).

Although this study provides significant findings, further exploration of several conceptual aspects remains crucial. First, this study did not address long-term knowledge retention, namely, whether the understanding gained through MITBAR remains persistent and can be applied during a real crisis (Ricciardi et al., 2021). Evaluation of learning persistence and knowledge generalization in the context of school readiness requires longitudinal studies with follow-up intervals of 3, 6, and 12 months (High et al., 2008). Second, the focus of this study is still limited to improving the cognitive dimension, so the effect of MITBAR on the affective and psychomotor dimensions, particularly in disaster anxiety regulation, self-efficacy during emergencies, and proactive mitigation behavioral initiatives, requires more in-depth methodological testing in the future (Yuliana et al., 2022).

Third, this study has not evaluated the effectiveness of MITBAR on individual child factors, such as cognitive style, prior individual technology experience, or baseline anxiety levels (Najamuddin et al., 2022). Identifying the user profiles that benefit most from this medium will support the implementation of more precise personalized learning in the future. Fourth, an ethnographic analysis of MITBAR's interactions with local belief systems, parental perceptions of technology-based education, and the media's adaptation to Indonesia's cultural diversity is needed (Chairani et al., 2024). Finally, to ensure sustainable implementation in Indonesia's heterogeneous education system, institutional and financial feasibility aspects, including cost analysis, infrastructure readiness, teacher training, and content maintenance, are variables that must be thoroughly assessed (Rahmawati, 2024).

Conclusion

This study developed MITBAR (Mitigasi Bencana Banjir Rob), an Augmented Reality-based learning media for children aged 5 to 6 years, using a research and development approach with the ADDIE model. The developed media consists of two integrated components: an AR mobile application and a printed AR book, both designed in accordance with early childhood cognitive characteristics. MITBAR presents tidal flood mitigation content covering definitions, natural and human-induced causes, disaster impacts, and mitigation stages across pre-disaster, emergency response, and post-disaster phases. The learning content is organized into 19 structured menus, supported by 3D visualizations, audio narration, and interactive activities. This structure reflects an instructional design intended to support children’s conceptual understanding and general knowledge related to disaster preparedness.

Results from expert validation and field implementation indicate that the media meet feasibility criteria and support short-term learning progression, as reflected in validation outcomes and pre-test/post-test results. The use of Augmented Reality facilitated the representation of abstract disaster mitigation concepts into more concrete forms appropriate for early childhood learning. Learning outcomes were primarily observed in gains in general knowledge and conceptual understanding relevant to components of school readiness. However, the findings are limited by the short evaluation period, small sample size, and focus on cognitive outcomes. Future research is recommended to employ longitudinal and multi-site designs and to examine affective, behavioral, and long-term preparedness outcomes across diverse early childhood education contexts.

Declarations

Author Contribution Statement

The author's contributions are as follows. Oktarina Dwi Handayani was responsible for conceptualization, methodology development, data curation, and preparation of the original draft, while Annisa Tri Tamiyati contributed to the investigation process. Wang Wu provided supervision and was involved in manuscript review and editing.

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Data Availability Statement

The dataset generated and analyzed during the research is available from the corresponding author upon reasonable request.

Declaration of Interests Statement

The author declares that there are no competing interests, financial or personal, that could have influenced the work reported in this manuscript.

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