



Integrating GIS and Augmented Reality in Flood Disaster Education: Effects on Students' Spatial Literacy and Preparedness

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ABSTRACT

Purpose of the study: This study investigates the effectiveness of GIS and augmented reality (AR) supported immersive flood learning in enhancing students' spatial literacy and flood preparedness within secondary geography education.

Methodology: A quasi experimental pretest–posttest control group design involved 107 Grade XI social science students from six senior high schools in Gorontalo City, Indonesia. The experimental group received GIS and AR supported immersive learning, while the control group received conventional instruction. Data were collected using a 40 item test measuring spatial literacy and flood preparedness. Data analysis employed descriptive statistics, normalized gain analysis, independent sample t tests, and effect size analysis.

Main Findings: Students in the experimental group achieved significantly higher posttest scores ($M = 84.72$, $SD = 6.41$) than the control group ($M = 71.58$, $SD = 7.24$). Statistical testing showed a significant difference between groups ($p < .05$), while effect size analysis indicated a large practical effect. GIS and AR supported immersive learning improved students' spatial interpretation, hazard analysis, contextual reasoning, and mitigation planning more effectively than conventional approaches across disaster related geography learning activities.

Novelty/Originality of this study: The findings provide empirical evidence that immersive geospatial learning integrating GIS and AR strengthens spatial cognition and disaster preparedness simultaneously within secondary geography education. Unlike previous studies emphasizing technological feasibility, the findings demonstrate the pedagogical role of immersive spatial learning in supporting contextual disaster understanding and environmental reasoning in flood prone educational settings.

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1. INTRODUCTION

Floods remain among the most frequent and destructive hydrometeorological disasters worldwide [1], [2]. Increasing flood impacts are associated with climate change, rapid urbanization, land-use conversion, and environmental degradation. Urban flood vulnerability has intensified particularly in developing and coastal regions where population growth intersects with inadequate environmental management and limited adaptive capacity [3], [4]. In Southeast Asia, flood disasters increasingly disrupt social, economic, and environmental systems,

emphasizing the urgent need for effective disaster risk reduction (DRR) strategies that strengthen community resilience and preparedness [5], [6], [7]. Beyond structural mitigation and emergency response, educational interventions have become an essential component of DRR because they facilitate environmental awareness, adaptive behavior, and participatory mitigation capacities among younger generations [8], [9], [10]. Consequently, disaster education plays a strategic role in preparing students to understand environmental risks and respond adaptively within their local socio-environmental contexts.

In Indonesia, flood disasters continue to occur recurrently across urban and rural regions, including Gorontalo Province, which has experienced increasing environmental pressures associated with land conversion, watershed degradation, and insufficient drainage infrastructure. Data from the Gorontalo Statistics Agency reported that numerous sub-districts experienced flooding in recent years, while severe flooding in 2024 inundated thousands of houses and displaced large numbers of residents [11], [12]. These recurring events indicate that disaster management cannot rely solely on infrastructure development and emergency response systems but also requires educational approaches capable of strengthening preparedness, environmental awareness, and adaptive capacities among students and communities. However, disaster learning in schools remains predominantly theoretical and textbook oriented, emphasizing memorization of disaster concepts rather than contextual understanding, spatial interpretation, and problem-solving competencies relevant to real environmental conditions [8], [13], [14]. Such conditions limit students' opportunities to develop practical preparedness skills and spatial reasoning abilities necessary for interpreting environmental risks and mitigation strategies.

One of the major challenges in disaster education is the limited integration of spatial literacy into geography learning practices. Spatial literacy refers to the ability to interpret spatial relationships, analyze geographic patterns, understand hazard distributions, and utilize geospatial information for decision making processes [15], [16]. Within flood disaster contexts, spatial literacy enables students to identify vulnerable areas, interpret hazard maps, analyze environmental changes, and understand interactions between hydrological systems and human activities [17]. Previous studies have demonstrated that Geographic Information Systems (GIS), thematic mapping, and digital geospatial visualization can strengthen students' understanding of environmental processes and disaster dynamics by connecting abstract geographic concepts with authentic spatial phenomena [18], [19]. Nevertheless, GIS supported disaster learning in schools often remains limited to map interpretation activities and has not sufficiently facilitated immersive and contextual spatial learning experiences capable of strengthening preparedness competencies.

Disaster education also requires the integration of higher order thinking skills (HOTS) to support analytical reasoning, evaluation, and contextual problem solving [20]-[22]. Flood disasters involve complex socio-environmental interactions that cannot be understood solely through factual memorization. Students need opportunities to critically evaluate environmental problems, assess mitigation alternatives, and formulate adaptive solutions relevant to local disaster conditions. Previous studies have shown that HOTS oriented learning strengthens critical thinking, collaborative inquiry, and contextual reasoning in geography and environmental education [19], [23]. However, existing disaster learning practices frequently emphasize declarative knowledge and procedural exercises, with limited opportunities for reflective inquiry and contextual environmental analysis supporting deeper conceptual understanding [24].

Ecopedagogy further complements disaster education by emphasizing ecological awareness, environmental ethics, and sustainability oriented learning perspectives [25], [26]. This approach encourages learners to critically examine relationships between environmental degradation, human activities, and disaster vulnerability while fostering social responsibility toward sustainable environmental management [27]-[29]. Within flood prone environments, ecopedagogical learning becomes particularly important because anthropogenic activities significantly influence hydrological disturbances and environmental degradation. Integrating ecopedagogy into disaster education therefore provides opportunities for students not only to understand disaster risks scientifically but also to develop ecological responsibility and participatory environmental awareness.

Recent advances in educational technology provide opportunities to strengthen disaster education through immersive and spatially oriented learning environments. The integration of GIS and augmented reality (AR) enables dynamic visualization of flood hazards, environmental changes, and mitigation scenarios in more interactive and contextual forms [18], [19], [30]. In this study, the learning materials utilized mobile based marker assisted AR visualization to simulate flood dynamics, hazard distribution, and mitigation scenarios interactively. GIS supported learning facilitates geospatial interpretation and spatial reasoning, whereas AR visualization transforms abstract disaster processes into immersive environmental representations. Such technology supported learning environments can strengthen experiential learning, increase cognitive engagement, and support contextual understanding of environmental risks and preparedness [31]-[33].

Despite these potentials, previous studies have predominantly examined GIS integration, AR visualization, spatial literacy, HOTS, or ecopedagogy separately rather than explaining how immersive geospatial learning environments facilitate spatial cognition and disaster preparedness simultaneously. Empirical evidence regarding the effectiveness of integrated GIS and AR supported learning within authentic secondary geography classrooms also remains limited, particularly in developing and disaster prone regions. Existing studies have

largely focused on technological feasibility, media usability, or conceptual development without sufficiently explaining the pedagogical mechanisms through which immersive geospatial learning strengthens students' spatial reasoning, environmental understanding, and preparedness competencies. This indicates a critical gap between technological innovation in disaster education and empirical evidence concerning its educational effectiveness within contextual classroom implementation.

Addressing this gap, the present study investigates the effectiveness of GIS and AR supported immersive learning in enhancing students' spatial literacy and flood preparedness within secondary geography education. The intervention integrates GIS based hazard mapping, AR visualization, HOTS oriented inquiry, and ecopedagogical learning activities into a contextual flood disaster learning framework. Unlike previous studies primarily emphasizing media development and technological feasibility, the findings provide empirical evidence regarding how immersive geospatial learning environments facilitate spatial cognition, contextual environmental reasoning, and preparedness competencies simultaneously. Therefore, the study contributes theoretically and pedagogically to disaster education by demonstrating the role of immersive geospatial learning in strengthening adaptive understanding and preparedness within flood prone educational contexts..

2. RESEARCH METHOD

2.1. Research Design

This study employed a quantitative quasi-experimental pretest–posttest control group design to evaluate the effectiveness of GIS and AR-supported immersive flood learning in improving students' spatial literacy and disaster preparedness. This design is suitable for examining causal effects in authentic classroom settings where random assignment is impractical [34]-[36]. Such designs are considered appropriate for evaluating instructional innovations and technology supported learning interventions in real educational environment [37]-[39].

The study involved experimental and control groups. The experimental group received GIS and AR-supported geospatial learning integrated with contextual flood case studies and HOTS-oriented activities, while the control group received conventional geography instruction. Pretest and posttest measures were used to assess learning gains and compare the effectiveness of both instructional approaches [37], [40], [41]. Such a design is widely used in disaster education research to evaluate technology-supported learning innovations. The intervention focused on flood disaster learning in Gorontalo City, Indonesia, integrating GIS, AR, contextual flood case studies, ecopedagogical activities, and HOTS-oriented exercises into a geospatial learning framework, which has been shown to enhance spatial reasoning, environmental awareness, and disaster preparedness [18], [19].

2.2 Participants and Sampling

The study involved 107 Grade XI social science students from six senior high schools in Gorontalo City, Indonesia, selected through purposive sampling based on the implementation of disaster-related geography learning and the availability of technological facilities [36], [41] [42]. The participants, consisting of 61 female and 46 male students aged 16–17 years, were assigned to experimental and control groups according to existing classroom arrangements. The experimental groups received GIS and AR-supported flood learning, while the control groups participated in conventional geography instruction. Grade XI students were selected due to the relevance of disaster mitigation and environmental topics in the geography curriculum and their capacity for analytical reasoning, spatial thinking, and problem-solving. The inclusion of multiple schools enabled implementation across diverse educational and flood-prone contexts [15], [21].

2.3 Research Procedures

The research procedure consisted of five sequential stages: preparation, pretest, intervention, posttest, and evaluation. These stages were systematically organized to ensure implementation consistency and facilitate comprehensive evaluation of the instructional intervention across participating schools. The intervention was conducted over six instructional sessions during geography learning activities related to flood disaster topics. The instructional framework consisted of four integrated components, namely GIS based hazard mapping, AR visualization, HOTS oriented inquiry activities, and ecopedagogical reflection. The overall learning workflow and system architecture are presented in Figure 1.

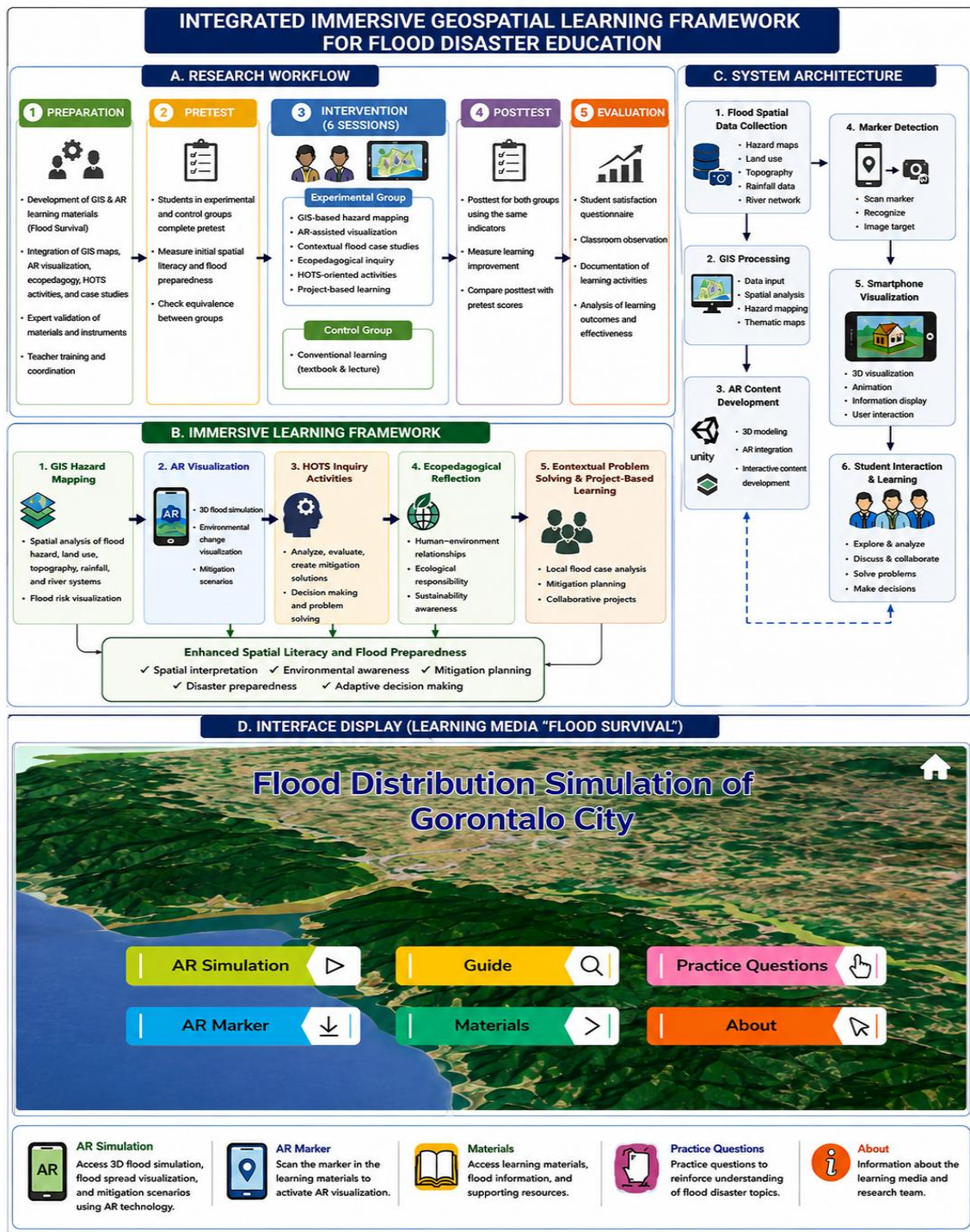


Figure 1. Architecture and Workflow of GIS and AR Supported Immersive Flood Disaster Learning

Preparation Stage

During the preparation stage, the *Flood Survival* learning materials were adapted from a previously developed prototype integrating GIS-based hazard maps, AR visualization, contextual flood case studies, ecopedagogical activities, and HOTS-oriented exercises. The materials and research instruments were validated through expert review to ensure content quality and technical functionality, while participating geography teachers received guidance to ensure consistent implementation across schools [18], [44].

Pretest Stage

Before the intervention, both groups completed pretests to assess baseline competencies in spatial literacy and flood preparedness, including understanding of flood causes, impacts, mitigation, and spatial interpretation.

The pretest also served to determine group comparability and provide a basis for measuring learning gains after the intervention.

Intervention Stage

The intervention was conducted during geography lessons on flood disasters. Students in the experimental groups engaged in GIS and AR-supported immersive geospatial learning involving map interpretation, spatial analysis, environmental reflection, and HOTS-oriented problem-solving activities, while AR visualization helped connect disaster concepts with real environmental conditions in Gorontalo City [15], [19], [44], [45]. The learning process also incorporated ecopedagogical principles to promote ecological awareness and sustainable mitigation practices [27], [28], [46]. In contrast, the control groups received conventional geography instruction through textbooks and teacher-centered explanations without GIS or AR integration.

Posttest Stage

Following the intervention, students completed posttests using the same indicators as the pretest to assess changes in spatial literacy and flood preparedness. The posttest results were compared with pretest scores and between groups to evaluate the effectiveness of GIS- and AR-supported immersive learning on disaster education outcomes.

Evaluation Stage

At the evaluation stage, students in the experimental groups completed a learning satisfaction questionnaire assessing usability, interactivity, visualization quality, contextual relevance, and overall learning experience. Classroom observations were also conducted to monitor implementation consistency, student participation, interaction patterns, and engagement during the intervention.

2.4 Research Instruments

The study used three main instruments consisting of (1) spatial literacy and flood preparedness tests, (2) student satisfaction questionnaires, and (3) classroom observation sheets. The cognitive test instrument consisted of 40 multiple-choice questions developed based on flood disaster concepts, spatial analysis, mitigation, adaptation, ecopedagogy, and contextual environmental issues in Gorontalo City. The questions were designed to measure conceptual understanding, spatial reasoning, analytical thinking, and contextual problem-solving skills.

Table 1. Grid of Spatial Literacy and Flood Preparedness Test Instrument

Variable	Dimension	Indicators	Item Numbers	Scale
Flood Preparedness	Conceptual understanding	Understanding flood causes, impacts, mitigation, and adaptation	1–15	Multiple choice
Spatial Literacy	Spatial interpretation	Ability to interpret flood hazard maps and spatial patterns	16–28	Multiple choice
Ecopedagogy	Environmental awareness	Understanding human-environment relationships and sustainability	29–34	Multiple choice
HOTS	Spatial problem solving	Ability to analyze and design mitigation solutions	35–40	Multiple choice

The student satisfaction questionnaire used a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The questionnaire evaluated students' perceptions regarding interactive learning attractiveness, GIS and AR visualization quality, ease of use, contextual relevance, and perceived learning effectiveness.

Table 2. Student Satisfaction Questionnaire Grid

Aspect	Indicators	Scale
Learning attractiveness	Interactive and engaging learning activities	Likert (1–5)
Visualization quality	Clarity of GIS maps and AR visualization	Likert (1–5)
Ease of use	Ease of navigation and accessibility	Likert (1–5)
Learning effectiveness	Improvement of understanding and preparedness	Likert (1–5)
Contextual relevance	Relevance to local flood conditions	Likert (1–5)

Content validity was evaluated through expert judgment involving geography education experts, educational technology experts, and language experts. Instrument validity was quantified using Aiken's V coefficient to ensure content relevance, clarity, and representativeness of the instrument items. The obtained Aiken's V values ranged from 0.82 to 0.93, indicating high content validity. Reliability testing was conducted

using Cronbach's alpha to measure internal consistency of the instrument constructs [47]. The instrument development process referred to established educational measurement principles [34], [40].

2.5 Data Collection Techniques

Data collection was conducted through tests, questionnaires, and classroom observations. Pretests and posttests were administered to measure students' spatial literacy and flood preparedness before and after the intervention. The tests were distributed directly during classroom learning activities in both experimental and control groups. Student satisfaction questionnaires were administered after the intervention to identify students' perceptions toward the interactive learning materials. Observation sheets were used to document classroom implementation, student participation, interaction patterns, and learning engagement during the experimental activities. Additional documentation included photographs of learning activities, GIS visualizations, and AR-based instructional implementation.

2.6 Data Analysis Techniques

Quantitative data analysis employed descriptive and inferential statistical techniques using SPSS software. Descriptive statistics included mean scores, percentages, standard deviations, minimum scores, and maximum scores to describe students' learning outcomes and satisfaction levels. Inferential statistical analysis was conducted to examine differences in learning outcomes between experimental and control groups [40], [48].

Learning improvement was analyzed using normalized gain (N Gain) analysis to identify magnitude of competency improvement following instructional intervention. Prior to hypothesis testing, assumption testing was conducted through Kolmogorov Smirnov normality testing and Levene's homogeneity testing to ensure data suitability for parametric analysis [41], [49]. Hypothesis testing employed an independent sample t test to determine whether significant differences existed between experimental and control groups. Statistical significance was established at the 0.05 level.

Effect size analysis using Cohen's d was also performed to determine practical significance of the instructional intervention. Cohen's d values of 0.20, 0.50, and 0.80 were interpreted as small, medium, and large effect sizes, respectively [40]. Integration of significance testing and effect size analysis enabled more comprehensive interpretation of both statistical and practical impacts of the geospatial learning intervention.

Table 3. Statistical Analysis Procedures

Analysis Technique	Purpose
Descriptive statistics	Describe learning outcomes and satisfaction levels
N Gain analysis	Measure competency improvement
Kolmogorov Smirnov test	Test data normality
Levene's test	Test homogeneity of variance
Independent sample t test	Compare experimental and control groups
Cohen's d	Measure practical effect size

2.7 Ethical Considerations

The study was conducted in accordance with educational research ethics principles. Participation of students and teachers was voluntary, and all participants were informed regarding the objectives and procedures of the study before data collection. Confidentiality and anonymity of participants were maintained throughout the research process. The use of digital learning media and spatial data was restricted exclusively to educational and research purposes.

3. RESULTS AND DISCUSSION

3.1. Pretest Results of Spatial Literacy and Flood Preparedness

The pretest was conducted prior to the instructional intervention to identify students' initial competencies related to spatial literacy and flood preparedness. The results indicate that students in both experimental and control groups demonstrated relatively similar baseline competencies before the implementation of the learning intervention. Most students showed limited abilities in interpreting flood spatial patterns, analyzing environmental relationships, and formulating contextual mitigation strategies associated with flood disasters in Gorontalo City.

Students particularly experienced difficulties in interpreting flood hazard maps, identifying spatial relationships between upstream and downstream areas, and analyzing the impacts of land-use change on flood vulnerability. These findings suggest that conventional geography learning had not yet optimally facilitated spatial reasoning and contextual disaster understanding. Similar findings have been reported in previous studies indicating that disaster-related concepts are frequently taught descriptively without sufficient support for spatial visualization and environmental interpretation [15], [44].

Table 4. Pretest Results of Experimental and Control Groups

Group	Number of Students	Mean	Standard Deviation	Minimum Score	Maximum Score
Experimental	54	54.26	8.14	38	71
Control	53	53.81	7.92	40	69

The relatively low pretest scores further indicate that students possessed limited preparedness competencies regarding flood mitigation and adaptation. Although most students were able to recognize general flood concepts, they encountered difficulties applying spatial analysis and contextual problem-solving skills to authentic environmental situations. These findings reinforce previous arguments emphasizing that disaster education requires interactive, contextual, and technology-supported learning approaches capable of strengthening students' analytical reasoning and environmental competencies [19], [28].

3.2. Implementation of GIS- and AR-Assisted Interactive Learning

The instructional intervention was implemented in six senior high schools in Gorontalo City involving Grade XI social science students. Experimental classes participated in immersive geospatial learning using GIS- and AR-supported flood learning materials, whereas control classes received conventional geography instruction through printed textbooks and teacher-centered explanations.

During the implementation process, students in the experimental groups actively interacted with GIS-based flood hazard maps, AR visualization, contextual videos, and inquiry-based learning activities. The instructional materials enabled students to analyze flood-prone areas spatially, identify environmental problems associated with rivers and drainage systems, and evaluate mitigation strategies relevant to local environmental conditions in Gorontalo City.



Figure 2. Real-world implementation of interactive learning media: (1) students engaged in collaborative learning activities during the classroom process; (2) utilization of digital devices to access interactive learning materials; (3) teacher-guided instruction using digital media in geography learning; and (4) application of Augmented Reality (AR) technology to support spatial understanding and student engagement

The integration of GIS and AR substantially increased student engagement during learning activities. Students demonstrated stronger participation in group discussions, spatial interpretation exercises, contextual inquiry, and mitigation-oriented project activities. AR visualization particularly facilitated students' understanding of flood distribution processes, river overflow dynamics, and relationships between topography and flood vulnerability through immersive environmental representation. These findings are consistent with previous studies demonstrating that interactive visualization technologies improve conceptual understanding and spatial reasoning within disaster education contexts [19], [44].

The instructional process also integrated ecopedagogical activities encouraging students to reflect critically on environmental problems and human activities contributing to flood vulnerability. Students conducted

simple environmental observations around school environments, identified drainage-related problems, and proposed sustainable mitigation strategies such as riverbank greening and waste management initiatives. Such activities supported the development of environmental awareness, contextual reasoning, and participatory problem-solving competencies.

3.3. Posttest Results of Spatial Literacy and Flood Preparedness

The posttest results demonstrated substantial improvement in students' spatial literacy and flood preparedness following the implementation of GIS- and AR-supported immersive learning materials. Students in the experimental group achieved considerably higher scores compared to those in the control group.

Table 5. Posttest Results of Experimental and Control Groups

Group	Number of Students	Mean	Standard Deviation	Minimum Score	Maximum Score
Experimental	54	84.72	6.41	71	96
Control	53	71.58	7.24	58	85

The improvement observed in the experimental group indicates that immersive geospatial learning supported students' understanding of flood concepts, spatial interpretation, and contextual mitigation planning more effectively than conventional instruction. Students demonstrated stronger competencies in interpreting flood hazard maps, analyzing environmental relationships, and formulating contextual adaptation strategies related to flood disasters.

GIS-supported visualization strengthened students' spatial literacy by enabling direct interpretation of geographic information through locally contextualized flood hazard maps. Students were able to identify vulnerable areas, analyze spatial relationships among environmental variables, and evaluate flood risk patterns based on actual environmental conditions in Gorontalo City. Previous studies similarly demonstrated that GIS-assisted learning improves spatial reasoning and contextual understanding within geography education [15], [44].

AR-supported visualization further enhanced conceptual understanding by transforming abstract flood processes into immersive three-dimensional environmental representations. Students reported that AR visualization facilitated clearer understanding of flood dynamics and increased engagement during learning activities. These findings align with previous research emphasizing the effectiveness of AR-assisted learning in supporting experiential and visual learning processes within environmental education [19].

3.4. N-Gain Analysis

The effectiveness of the instructional intervention was further examined using normalized gain (N-Gain) analysis to identify the magnitude of competency improvement in each group.

Table 6. N-Gain Results

Group	Mean Pretest	Mean Posttest	N-Gain Score	Classification
Experimental	54.26	84.72	0.67	Moderate
Control	53.81	71.58	0.38	Moderate

The experimental group achieved a substantially higher N-Gain score than the control group, indicating that GIS- and AR-supported immersive learning was more effective in improving students' spatial literacy and flood preparedness competencies.

The higher improvement observed in the experimental group may be associated with several pedagogical factors. First, immersive spatial visualization enabled students to analyze flood-related phenomena more contextually and analytically. Second, interactive learning activities encouraged active participation, inquiry, and contextual problem-solving rather than passive memorization. Third, the integration of ecopedagogical perspectives strengthened environmental awareness by connecting flood problems with human-environment interactions and sustainability issues.

These findings support previous studies emphasizing that contextual and technology-supported disaster education contributes positively to analytical reasoning, environmental literacy, and preparedness competencies among learners [13], [28].

3.5 Hypothesis Testing

An independent sample t-test was conducted to examine whether significant differences existed between the experimental and control groups following implementation of GIS- and AR-supported immersive learning materials. Prior to hypothesis testing, assumption testing was conducted using the Kolmogorov-Smirnov normality test and Levene's homogeneity test. The results indicated that the data were normally distributed and demonstrated homogeneous variance between groups, confirming that the assumptions required for parametric statistical analysis were fulfilled.

Table 7. Independent Sample t-Test Results

Variable	t-value	Sig. (2-tailed)	Interpretation
Spatial Literacy and Flood Preparedness	4.218	0.001	Significant Difference

The independent sample t-test produced a significance value of 0.001, which was lower than the 0.05 significance threshold. These results indicate a statistically significant difference between students in the experimental and control groups following the instructional intervention. The obtained t-value demonstrates that GIS- and AR-supported immersive learning contributed positively to students' learning outcomes.

Students in the experimental group demonstrated stronger competencies in spatial literacy and flood preparedness compared to students who learned through conventional instructional approaches. They showed improved abilities in interpreting flood hazard maps, identifying spatial relationships among environmental variables, analyzing vulnerable areas, and formulating contextual mitigation strategies associated with flood disasters in Gorontalo City.

The improvement in learning outcomes was associated with the integration of immersive visualization, GIS-supported spatial analysis, and contextual environmental learning activities. GIS maps facilitated students' interpretation of flood distribution patterns more effectively, while AR visualization supported understanding of flood processes through interactive and concrete environmental representation. These findings align with previous studies emphasizing that geospatial technologies strengthen spatial reasoning and conceptual understanding within geography and disaster education [15], [44].

The instructional activities also integrated HOTS-oriented inquiry and ecopedagogical perspectives encouraging students to think critically about environmental problems and disaster mitigation practices. Students were able to connect theoretical concepts with authentic environmental conditions and develop reflective perspectives regarding sustainable environmental management. These findings are consistent with previous studies demonstrating that contextual and technology-supported disaster education contributes positively to analytical thinking, preparedness competencies, and environmental awareness [19], [29]. To complement significance testing, effect size analysis using Cohen's d was conducted to determine the practical significance of the intervention.

Table 8. Student Satisfaction Results

Variable	Cohen's d	Interpretation
Spatial Literacy and Flood Preparedness	1.02	Large Effect

The obtained Cohen's d value indicates that the intervention produced a large practical effect on students' spatial literacy and flood preparedness competencies. This finding suggests that the effectiveness of immersive geospatial learning was not only statistically significant but also educationally meaningful within disaster education contexts

3.6. Student Satisfaction toward Interactive Learning Materials

Student satisfaction questionnaires were distributed following the implementation process to evaluate students' perceptions regarding the immersive learning materials. Overall, students demonstrated highly positive responses toward the GIS- and AR-supported learning experience.

Table 9. Student Satisfaction Results

Aspect	Mean Score	Category
Learning attractiveness	4.71	Very High
Visualization quality	4.76	Very High
Ease of use	4.58	Very High
Learning effectiveness	4.73	Very High
Contextual relevance	4.81	Very High
Average	4.72	Very High

Students reported that GIS maps and AR visualization helped them understand flood-prone areas more clearly while making learning activities more engaging and interactive. The contextual integration of flood cases from Gorontalo City also increased students' awareness regarding environmental problems occurring within their surrounding communities. The highest score was obtained in the contextual relevance aspect, indicating that students strongly valued instructional materials directly connected to their local environmental conditions. These findings reinforce previous arguments emphasizing the importance of place-based and contextual disaster education in supporting meaningful learning experiences, environmental awareness, and adaptive preparedness competencies.

The findings of the present study demonstrate that GIS- and AR-supported immersive learning significantly improved students' spatial literacy and flood preparedness compared to conventional geography

instruction. Students in the experimental group achieved higher competencies in flood hazard interpretation, spatial analysis, contextual mitigation planning, and environmental problem-solving after participating in the intervention. These findings indicate that integrating geospatial technologies and immersive visualization into disaster education creates more meaningful and contextual learning experiences that strengthen students' understanding of environmental risks and adaptive preparedness competencies. Similar findings have been reported in previous studies emphasizing that disaster education becomes more effective when supported by contextual learning environments and digital geospatial technologies [19], [44].

The improvement in students' spatial literacy reflects the important pedagogical role of GIS-supported learning in facilitating spatial cognition and geospatial reasoning. Students were able to interpret flood hazard maps, identify vulnerable areas, analyze relationships among environmental variables, and understand interactions between land use, topography, rainfall, and flood occurrence in Gorontalo City more effectively. The use of locally contextualized flood hazard maps enabled students to connect abstract geographic concepts with authentic environmental conditions surrounding their communities. From a spatial cognition perspective, geospatial visualization supports learners in constructing mental representations of environmental phenomena and understanding spatial relationships through contextual interpretation and analytical reasoning [15], [50]. These findings suggest that GIS-supported disaster education not only strengthens conceptual understanding but also enhances students' capacity to critically interpret environmental risks and disaster vulnerability patterns [20].

The integration of GIS into flood disaster learning also facilitated experiential and student-centered learning processes. Rather than passively memorizing disaster-related concepts, students actively engaged in map interpretation, environmental analysis, and contextual problem-solving activities. Such learning processes are consistent with constructivist perspectives emphasizing that meaningful learning occurs when students actively construct knowledge through interaction with authentic environmental contexts. Previous studies similarly reported that GIS-supported learning environments strengthen environmental awareness, spatial reasoning, and disaster risk reduction understanding through the integration of real environmental data into classroom activities [2], [18]. The present findings extend previous research by demonstrating that GIS-supported immersive learning can simultaneously strengthen spatial literacy and flood preparedness within secondary geography education contexts.

AR supported visualization became another important factor contributing to learning improvement in the experimental group. Through immersive visualization, students interacted with three-dimensional representations illustrating flood processes, hazard distribution, environmental impacts, and mitigation scenarios dynamically. This interactive representation reduced the abstractness of hydrological processes and enabled students to observe environmental changes more concretely. From an experiential learning perspective, immersive visualization facilitates deeper conceptual understanding because learners interact directly with contextual environmental representations rather than relying solely on textual explanation. Previous studies have similarly shown that AR-assisted learning enhances conceptual understanding, cognitive engagement, and spatial reasoning through interactive environmental visualization [19], [45]. In the present study, AR-supported learning enabled students to understand flood mechanisms and mitigation strategies more meaningfully because abstract disaster concepts were transformed into observable and contextual experiences.

The effectiveness of AR-supported learning can also be explained through cognitive engagement processes. Interactive visualization integrates visual, spatial, and contextual information simultaneously, allowing students to process environmental phenomena through multimodal learning experiences. Such immersive interaction potentially supports deeper conceptual processing and improves students' ability to connect environmental causes, disaster impacts, and mitigation strategies within authentic geographic contexts. In addition, AR-supported learning increased students' participation and motivation because learners experienced more dynamic instructional processes compared to conventional textbook-oriented learning environments. These findings support previous studies demonstrating that multimedia and immersive learning environments improve engagement, participation, and conceptual understanding in geography and environmental education [51], [52], [53].

The improvement in flood preparedness competencies was also strongly associated with the integration of HOTS-oriented learning activities within the instructional materials. Students were encouraged to analyze flood causes, evaluate environmental conditions, interpret hazard maps, and formulate contextual mitigation strategies based on environmental problems occurring in Gorontalo City. Such activities promoted analytical reasoning, evaluation, and contextual problem-solving rather than factual memorization alone. Previous studies have emphasized that HOTS-oriented disaster education strengthens critical thinking, environmental reasoning, and adaptive problem-solving competencies among learners [21], [54]. The findings therefore indicate that integrating higher-order thinking activities into immersive geospatial learning environments supports students in developing contextual disaster preparedness competencies relevant to real environmental challenges.

The ecopedagogical orientation integrated into the learning materials further contributed to strengthening environmental awareness and reflective understanding regarding disaster vulnerability. The instructional activities emphasized relationships between human activities and flood disasters, particularly concerning land conversion,

drainage blockage, waste disposal, and watershed degradation in Gorontalo City. Through contextual reflection and environmental inquiry, students were encouraged to recognize that flood disasters are influenced not only by natural processes but also by unsustainable environmental practices. These findings align with previous studies explaining that ecopedagogical learning promotes ecological awareness, environmental ethics, and critical reflection regarding socio-environmental relationships [28], [29]. Ecopedagogy therefore complements immersive disaster education by encouraging students to develop participatory attitudes and environmental responsibility within their local communities [26].

Another important finding concerns the role of contextual and place-based learning in strengthening disaster preparedness. The learning materials were developed using local flood characteristics, spatial data, and environmental conditions from Gorontalo City, increasing the relevance and authenticity of learning experiences. Contextualization enabled students to perceive flood disasters not as abstract geographic concepts but as real environmental challenges directly connected to their daily lives and surrounding environments. Previous studies have similarly demonstrated that place-based disaster education strengthens preparedness and environmental awareness because learners perceive the instructional content as meaningful and socially relevant [8], [31]. The present findings reinforce the importance of contextual geospatial learning in promoting adaptive understanding and localized disaster preparedness competencies.

The novelty of this study lies in the integrated application of GIS, AR, HOTS oriented instruction, spatial literacy development, and ecopedagogical perspectives within a single immersive disaster education framework. While previous studies have generally examined GIS, AR, or disaster preparedness separately, the present study empirically demonstrates how these components interact synergistically to strengthen both spatial cognition and contextual flood preparedness simultaneously in secondary geography education. Furthermore, the use of locally contextualized flood hazard data from Gorontalo City contributes a place-based dimension that enhances the authenticity and relevance of immersive geospatial learning. This multidimensional integration provides a more comprehensive pedagogical model for disaster education compared to previous technology-oriented approaches that focused primarily on conceptual understanding or technological engagement alone.

From a practical perspective, the findings have important implications for geography and disaster education. The integration of immersive geospatial technologies can support teachers in developing more interactive, contextual, and student-centered learning environments that encourage critical thinking and environmental responsibility. Educational institutions may consider incorporating GIS- and AR-based disaster learning into geography curricula to strengthen students' preparedness competencies and adaptive awareness toward environmental risks. In addition, policymakers and curriculum developers may use these findings as a reference for designing technology-supported disaster education programs that integrate spatial literacy, HOTS, and environmental ethics simultaneously. The findings also imply that effective disaster education should not only transfer knowledge about hazards but also foster participatory awareness, contextual reasoning, and sustainable environmental behavior among students.

Despite the educational potential of GIS- and AR-supported immersive learning, several implementation challenges should also be critically acknowledged. The effectiveness of immersive geospatial learning environments depends heavily on technological infrastructure, digital literacy, and teacher readiness. Schools with limited access to digital devices and stable technological support may experience difficulties implementing AR-assisted learning consistently. In addition, immersive visualization environments may increase cognitive load when students simultaneously process complex spatial information, digital interaction, and contextual problem-solving tasks. Without adequate instructional guidance, excessive multimedia stimulation may reduce learning efficiency and overwhelm students cognitively. These findings indicate that successful implementation of immersive disaster education requires not only technological innovation but also appropriate pedagogical design, teacher facilitation, and equitable access to digital learning resources.

From a pedagogical perspective, the findings demonstrate that integrating GIS, AR, HOTS, spatial literacy, and ecopedagogical perspectives creates a multidimensional learning environment capable of strengthening both conceptual understanding and preparedness competencies. Immersive geospatial learning enables students to engage actively in contextual environmental analysis, spatial interpretation, and mitigation-oriented problem-solving processes while simultaneously developing environmental responsibility and adaptive awareness [55]. Previous studies have emphasized that effective disaster education should integrate analytical reasoning, contextual learning, environmental ethics, and participatory experiences to strengthen disaster risk reduction competencies [9], [13]. The present findings therefore contribute to disaster education literature by providing empirical evidence regarding the pedagogical mechanisms through which immersive geospatial learning facilitates spatial cognition and disaster preparedness simultaneously within secondary geography education [32], [56].

Several limitations should nevertheless be acknowledged. The intervention focused primarily on short-term instructional outcomes, meaning that the sustainability of disaster preparedness behavior and environmental decision-making could not yet be examined comprehensively. In addition, immersive geospatial learning environments require adequate technological infrastructure, digital literacy, and teacher facilitation, which may

influence implementation effectiveness across different educational settings. The simultaneous integration of GIS analysis, AR visualization, and contextual problem-solving activities may also increase cognitive complexity for some learners, particularly within resource-limited classrooms. These limitations indicate that the effectiveness of immersive disaster education depends not only on technological innovation but also on pedagogical design and institutional readiness.

Future studies are recommended to investigate the long-term impacts of immersive geospatial learning on environmental behavior, adaptive decision-making, and disaster preparedness sustainability. Further research may also explore the integration of Web GIS, mobile-based disaster learning applications, virtual simulations, and collaborative community-based disaster projects to strengthen experiential and participatory disaster education. Comparative studies involving different disaster contexts and educational levels may provide broader insights regarding the effectiveness of immersive geospatial technologies in disaster education settings.

4. CONCLUSION

This study demonstrates that GIS- and AR-supported immersive geospatial learning significantly improves students' spatial literacy and flood preparedness compared to conventional geography instruction. Students who participated in the intervention achieved higher posttest scores, greater learning gains ($N\text{-Gain} = 0.67$), and significantly better learning outcomes than those in the control group ($p = 0.001$; Cohen's $d = 1.02$). The integration of GIS-based spatial analysis, AR-assisted visualization, contextual flood case studies, HOTS-oriented activities, and ecopedagogical learning effectively enhanced students' abilities to interpret flood hazard maps, analyze environmental relationships, identify vulnerable areas, and formulate contextual mitigation strategies. The findings indicate that immersive geospatial learning provides meaningful, contextual, and student-centered learning experiences that strengthen both spatial cognition and disaster preparedness competencies. The high level of student satisfaction further confirms the attractiveness, usability, and contextual relevance of the learning materials. Therefore, integrating GIS and AR technologies into geography and disaster education offers a promising pedagogical approach for developing environmental awareness, critical thinking, and adaptive preparedness among secondary school students. Future research should therefore investigate the long-term impacts of immersive geospatial learning on preparedness behavior, environmental awareness, and adaptive decision-making. Further exploration involving Web GIS, virtual simulation, mobile-based disaster learning, and participatory community-based projects may provide broader insights into the role of immersive geospatial technologies in strengthening disaster education across different environmental contexts and educational levels.

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AUTHOR CONTRIBUTIONS

M.I.L.P. conceptualized and designed the study, developed the GIS- and AR-assisted interactive learning materials, coordinated the research implementation, and prepared the original manuscript draft. R. conducted data collection in the participating senior high schools, administered the experimental procedures, and performed statistical data analysis. W.K and H. contributed to the interpretation of findings, development of the discussion section, validation and refinement of the instructional materials, and critical revision of the manuscript. All authors reviewed, revised, and approved the final version of the manuscript for publication.

INFORMED CONSENT STATEMENT

Informed consent was obtained from all participants prior to data collection. Participants were informed about the study objectives, procedures, and voluntary nature of their involvement.

CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funding body had no role in the design of the study; in data collection, analysis, or interpretation; in manuscript preparation; or in the decision to publish.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

Not applicable.

REFERENCES

- [1] K. M. Andreadis, O. E. J. Wing, E. Colven, C. J. Gleason, P. D. Bates, and C. M. Brown, "Urbanizing the floodplain: global changes of imperviousness in flood-prone areas," *Environ. Res. Lett.*, vol. 17, no. 10, 2022, doi: 10.1088/1748-

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- 9326/ac9197.
- [2] J. Yang, J. Wang, Y. Hu, B. Li, J. Zhao, and Z. Liang, "Flood risk mapping for the area with mixed floods and human impact: a case study of Yarkant River Basin in Xinjiang, China," *Environ. Res. Commun.*, vol. 5, no. 9, 2023, doi: 10.1088/2515-7620/acf0a2.
 - [3] N. Laeni, M. van den Brink, T. Busscher, H. Ovink, and J. Arts, "Building local institutional capacities for urban flood adaptation: Lessons from the water as leverage program in Semarang, Indonesia," *Sustain.*, vol. 12, no. 23, 2020, doi: 10.3390/su122310104.
 - [4] N. Laeni, M. van den Brink, and J. Arts, "Institutional conditions for inclusive, flood resilient urban deltas: A comparative institutional analysis of two international resilience programs in southeast asia," *Water (Switzerland)*, vol. 13, no. 18, 2021, doi: 10.3390/w13182478.
 - [5] A. Fahrudin, R. H. R. Andayani, W. K. G. Albert, I. Hindarsah, M. Z. Hakim, and H. Yusuf, "The impact of social protection on community resilience in the context of climate change and natural disaster," *J. Ecohumanism*, vol. 3, no. 8, 2024, doi: 10.62754/joe.v3i8.4824.
 - [6] R. Rahat, P. Pradhananga, and M. ElZomor, "Evaluation of safe-to-fail flood solution alternatives and integration of safe-to-fail concept in AEC education to develop resilient coastal cities," *Int. J. Disaster Resil. Built Environ.*, vol. 15, no. 2, 2024, doi: 10.1108/IJDRBE-04-2022-0041.
 - [7] P. A. Kamil, S. Utaya, Sumarmi, and D. H. Utomo, "Strengthen disaster preparedness for effective response on young people through geography education: A case study at school in the tsunami affected area of Banda Aceh City, Indonesia," in *IOP Conference Series: Earth and Environmental Science*, 2020, doi: 10.1088/1755-1315/412/1/012016.
 - [8] R. Hoffmann and D. Blecha, "Education and disaster vulnerability in Southeast Asia: Evidence and policy implications," *Sustain.*, vol. 12, no. 4, 2020, doi: 10.3390/su12041401.
 - [9] I. Pal, V. Raj, A. Pal, and K. Sukwanchai, "Disaster risk reduction education (DRRE) and resilience in Asia-Pacific," in *Disaster Resilience and Sustainability: Adaptation for Sustainable Development*, 2021, doi: 10.1016/B978-0-323-85195-4.00004-4.
 - [10] L. D. C. H. N. Kalpana, A. B. Jayasinghe, C. C. Abenayake, and P. N. P. Wijayawardana, "Network Centrality Assessment (NCA): Assessing the transport network resilience to urban flooding," *J. South Asian Logist. Transp.*, vol. 1, no. 1, 2021, doi: 10.4038/jsalt.v1i1.29.
 - [11] S. Sumiyati and R. J. Emha, "Makna idiomatik dalam majalah berita *Tempo* [Idiomatic meaning in the *Tempo* news magazine]," in *Proc. Semin. Nas. Sasindo*, 2022, doi: 10.32493/sns.v2i2.22079.
 - [12] Badan Pusat Statistik Kota Gorontalo, "Jumlah Kelurahan yang Mengalami Bencana Alam [Number of Sub-districts Experiencing Natural Disasters]," 2024.
 - [13] N. N. Hawa, S. Z. S. Zakaria, M. R. Razman, N. A. Majid, A. M. Taib, and Emrizal, "Element of disaster risk reduction in geography education in Malaysia," *Sustain.*, vol. 15, no. 2, 2023, doi: 10.3390/su15021326.
 - [14] D. Partini and A. N. Hidayat, "Disaster risk reduction efforts through education in Indonesia: A literature review," in *IOP Conference Series: Earth and Environmental Science*, 2024, doi: 10.1088/1755-1315/1314/1/012049.
 - [15] J. J. Kerski, "Geo-awareness, geo-enablement, geotechnologies, citizen science, and storytelling: Geography on the world stage," *Geogr. Compass*, vol. 9, no. 1, 2015, doi: 10.1111/gec3.12193.
 - [16] M. Zhang and J. Wang, "Trend analysis of global disaster education research based on scientific knowledge graphs," *Sustain.*, vol. 14, no. 3, 2022, doi: 10.3390/su14031492.
 - [17] K. Jung *et al.*, "Assessing the suitability of the flood defense policy of republic of korea for risk reduction in local rivers," *Water (Switzerland)*, vol. 15, no. 22, 2023, doi: 10.3390/w15223908.
 - [18] J. Li *et al.*, "Web GIS for sustainable education: Towards natural disaster education for high school students," *Sustain.*, vol. 14, no. 5, 2022, doi: 10.3390/su14052694.
 - [19] S. Safitri, J. Juhadi, and A. Aji, "Ecoliteracy learning design with augmented reality-based SETS approach for flood disaster education," *IJORER Int. J. Recent Educ. Res.*, vol. 5, no. 3, 2024, doi: 10.46245/ijorer.v5i3.610.
 - [20] B. Abdimanapov, S. Kumarbekuly, and I. Gaisin, "Technology for achieving learning objectives through a system-activity approach and the development of critical thinking in geography studies," *J. Ecohumanism*, vol. 3, no. 8, 2024, doi: 10.62754/joe.v3i8.5797.
 - [21] A. Zohar and Y. J. Dori, "Higher order thinking skills and low-achieving students: Are they mutually exclusive?," *J. Learn. Sci.*, vol. 12, no. 2, 2003, doi: 10.1207/S15327809JLS1202_1.
 - [22] A. Agustina and R. A. Rahman, "Structured inquiry learning: Enhancing critical thinking and conceptual understanding through productive questioning," *J. Acad. Biol. Biol. Educ.*, vol. 2, no. 2, pp. 165–171, 2AD, doi: 10.37251/jouabe.v2i2.2604.
 - [23] R. A. Tyas, Pujianto, and Suyanta, "Volcanoes Disaster Risk Reduction in Science Education Curriculum," in *Proceedings of the 7th International Conference on Research, Implementation, and Education of Mathematics and Sciences (ICRIEMS 2020)*, 2021, doi: 10.2991/assehr.k.210305.098.
 - [24] H. Tomlinson, B., & Masuhara, *The Complete Guide to the Theory and Practice of Materials Development for Language Teaching*. 2018. doi: 10.14712/25337637.2025.11.
 - [25] A. Fauzi, S. Fitriasarri, and D. I. Muthaquin, "Development of student ecological intelligence through the implementation of ecopedagogy," in *Proceedings of the Annual Civic Education Conference (ACEC 2021)*, 2022, doi: 10.2991/assehr.k.220108.099.
 - [26] P. I. Wardhani, H. S. Palupi, W. Widyatmoko, M. Musiyam, S. H. N. Hafida, and E. S. Pratiwi, "Implementation of environmental ethics in ecopedagogy-based geography learning by teachers on environmental sustainability," in *Proceedings of the 7th Progressive and Fun Education International Conference (PROFUNEDU 2022)*, 2022, doi: 10.2991/978-2-494069-71-8_6.
 - [27] M. Kinyota, "Implementing ecopedagogy in highly centralised curricula contexts: a critical analysis of an environmental education course taught at one Tanzanian university," *Int. Stud. Sociol. Educ.*, vol. 30, no. 1–2, 2021, doi:

- 10.1080/09620214.2020.1854824.
- [28] G. W. Misiaszek, "Ecopedagogy: teaching critical literacies of 'development', 'sustainability', and 'sustainable development,'" *Teach. High. Educ.*, vol. 25, no. 5, 2020, doi: 10.1080/13562517.2019.1586668.
- [29] G. W. Misiaszek, "Countering post-truths through ecopedagogical literacies: Teaching to critically read 'development' and 'sustainable development,'" *J. Integr. Philos. Theory*, vol. 52, no. 7, 2020, doi: 10.1080/00131857.2019.1680362.
- [30] A. I. Fazrin, D. N. Agnafia, and A. Mashuri, "Development of augmented reality (AR) media to improve learning outcomes on earth structure for eighth grade students," *Integr. Sci. Educ. J.*, vol. 6, no. 2, pp. 115–122, 2025, doi: 10.37251/isej.v6i2.1762.
- [31] A. Khadka, C. J. Li, S. W. Stanis, and M. Morgan, "Unpacking the power of place-based education in climate change communication," *Appl. Environ. Educ. Commun.*, vol. 20, no. 1, pp. 77–91, 2021, doi: 10.1080/1533015X.2020.1719238.
- [32] P. H. Pratiwi, S. I. A. Dwiningrum, and D. R. S. Sumunar, "Integrated Disaster Risk Management in the Education Process in Schools," *J. Integr. Disaster Risk Manag.*, vol. 13, no. 1, 2023, doi: 10.5595/001C.91284.
- [33] H. Riah, "Augmented reality-based interactive learning media: Enhancing understanding of chemical bonding concepts," *J. Chem. Learn. Innov.*, vol. 2, no. 1, pp. 55–63, 2025, doi: 10.37251/jocli.v2i1.1919.
- [34] J. W. Creswell and C. N. Poth, *Qualitative Inquiry and Research Design: Choosing Among Five Approaches*. Sage Publication, vol. Fourth Edi. Sage Publication, 2017.
- [35] M. Gall, J. P. Gall, and W. R. Borg, *Educational Research: An Introduction (7th ed.)*. Boston: Allyn & Bacon, 2003.
- [36] F. Fetmirwati, L. G. Franco, and M. T. G. Tadena, "Exploring the guided inquiry learning model in biology practicum: its impact on students' scientific attitudes and cognitive knowledge," *J. Acad. Biol. Biol. Educ.*, vol. 2, no. 1, pp. 26–34, Jun. 2025, doi: 10.37251/jouabe.v2i1.1642.
- [37] D. T. Shadish, W. R., Cook, T. D., & Campbell, "Experimental and quasi-experimental designs for generalized causal inference. Houghton Mifflin,," *Hought. Mifflin.*, vol. 41, no. 1, 2002.
- [38] W. Dick, L. Carey, and J. O. Carey, *The Systematic Design of Instruction*, annotated ed. Hoboken, NJ, USA: Pearson, 2021.
- [39] M. Q. Patton, "Qualitative Research & Evaluation Methods: Integrating Theory and Practice - Michael Quinn Patton - Google Books," 2014.
- [40] L. Cohen, L. Manion, and K. Morrison, *Research Methods in Education*. 2017. doi: 10.4324/9781315456539.
- [41] J. Fraenkel, N. Wallen, and H. Hyun, *How to Design and Evaluate Research in Education*, vol. 60. 2022.
- [42] D. N. Junita and R. D. Prasad, "The effect of using english animation videos on students' speaking ability," *J. Lang. Lit. Educ. Res.*, vol. 1, no. 2, pp. 39–44, 2024, doi: 10.37251/jolle.v1i2.1063.
- [43] P. E. Bajuri, Y. G. Sosa, K. Mosime, and C. F. Day, "Community interest and motivation toward recreational sports participation in solo car free day public space," *Multidiscip. J. Tour. Hosp. Sport Phys. Educ.*, vol. 2, no. 2, pp. 231–239, 2025, doi: 10.37251/jthpe.v2i2.3294.
- [44] Y. Y. Li and S. C. Liu, "Examining Taiwanese students' views on climate change and the teaching of climate change in the context of higher education," *Res. Sci. & Technological Educ.*, 2022, doi: 10.1080/02635143.2020.1830268.
- [45] K. B. Romualdi, A. Sudrajat, and A. Aman, "Development of genially interactive multimedia on materials for the national movement organization for middle school students," *AL-ISHLAH J. Pendidik.*, vol. 15, no. 2, 2023, doi: 10.35445/alishlah.v15i2.3139.
- [46] G. W. Misiaszek, "Ecopedagogy as an element of citizenship education: The dialectic of global/local spheres of citizenship and critical environmental pedagogies," *Int. Rev. Educ.*, vol. 62, no. 5, 2016, doi: 10.1007/s11159-016-9587-0.
- [47] M. Tavakol and R. Dennick, "Making sense of Cronbach's alpha," 2011. doi: 10.5116/ijme.4dfb.8dfd.
- [48] A. Field, "Discovering Statistic Using IBM SPSS Statistic 5th," *Sage Publ.*, vol. 53, no. 9, 2017.
- [49] J. Pallant, *SPSS: Survival Manual: A Step by Step Guide to Data Analysis Using IBM SPSS: 7th Edition*. 2020. doi: 10.4324/9781003117452.
- [50] M. Vojtek, "Indicator-based approach for fluvial flood risk assessment at municipal level in Slovakia," *Sci. Rep.*, vol. 13, no. 1, 2023, doi: 10.1038/s41598-023-32239-7.
- [51] R. Rizal, D. Rusdiana, W. Setiawan, and P. Siahaan, "Learning management system supported smartphone (lms3): online learning application in physics for school course to enhance digital literacy of pre-service physics teachers," *J. Technol. Sci. Educ.*, vol. 12, no. 1, 2022, doi: 10.3926/JOTSE.1049.
- [52] Y. T. Widiharto, K. Fajriyah, and K. Kiswoyo, "PINSAs learning media (cow digestion billboard) on healthy food theme," *Indones. J. Educ. Res. Rev.*, vol. 4, no. 2, 2021, doi: 10.23887/ijerr.v4i2.30414.
- [53] I. Aryani*, D. Aziz Pramudita, N. Nauli Sinangkling, and I. Destya Adi Tama, "Development of android-based learning media applications to determine validity and feasibility for grade VII middle school students on ecosystem material," *J. IPA Pembelajaran IPA*, vol. 7, no. 1, 2023, doi: 10.24815/jipi.v7i1.28885.
- [54] S. Ridha, S. Utaya, S. Bachri, B. Handoyo, P. A. Kamil, and A. W. Abdi, "Spatial Thinking and Decision-Making Abilities to Learn about Disaster Preparedness," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 630, no. 1, 2021, doi: 10.1088/1755-1315/630/1/012017.
- [55] A. Oberle, F. Araya, and S. Alvarez, "Priorities for Pan-American Geography Education: Needs and Trends," *Educ. Sci.*, vol. 14, no. 1, 2024, doi: 10.3390/educsci14010064.
- [56] S. N. Purnomo, W. Widiyanto, A. D. Novyanto, and A. I. Pratiwi, "Flood disaster mitigation measure recommendations based on flood hazard and risk assessment: a case study in Brebes Regency, North Coast of Java," in *E3S Web of Conferences*, 2023. doi: 10.1051/e3sconf/202346401018.