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Inquiry-Based and Digital Simulation-Assisted IPAS Learning to Strengthen Science Literacy and Flood Mitigation Behavior among Urban Elementary School Students

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ABSTRACT

Background. Urban flooding is a contextual environmental problem that requires students to understand scientific processes and develop responsible environmental responses. Elementary science learning therefore needs to provide opportunities for students to investigate authentic environmental phenomena and connect scientific knowledge with everyday problems.

Purpose. This study aimed to examine the implementation of inquiry-based and digital simulation-assisted IPAS learning and its potential to improve elementary students' science literacy and flood mitigation behavior.

Method. This study employed a quantitative approach with a quasi-experimental one-group pretest-posttest design. The learning intervention integrated inquiry activities with digital simulations of urban flood phenomena. Data were collected using a science literacy test, a flood mitigation behavior questionnaire, and learning observation sheets. Instrument validity was assessed using expert judgment and Aiken's V, while reliability was examined using Cronbach's Alpha. Data were analyzed using descriptive statistics and normalized gain (N-Gain).

Results. Students' mean science literacy score increased from 61.25 on the pretest to 84.60 on the posttest, representing an increase of 23.35 points. The overall N-Gain was 0.71, categorized as high

Conclusion. The findings indicate that inquiry-based and digital simulation-assisted IPAS learning can support the development of elementary students' science literacy and flood mitigation-related awareness and behavior. The approach provides a contextual learning experience that connects scientific investigation with authentic urban environmental problems.

KEYWORDS

Digital Simulation, Elementary Education, Flood Mitigation, Inquiry-Based Learning, Science Literacy.

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INTRODUCTION

The development of 21st-century education emphasizes the importance of preparing students with scientific literacy, critical thinking skills, problem-solving abilities, and environmental awareness (Rahmadhani et al., 2021). Scientific literacy is no longer limited to understanding scientific concepts but also involves the ability to apply scientific knowledge in real-life situations,

evaluate evidence, and make responsible decisions related to scientific and environmental issues. The Programme for International Student Assessment (PISA) framework defines science literacy as the ability to engage with science-related issues and ideas as a reflective citizen. Students with strong science literacy are expected to explain phenomena scientifically, evaluate scientific investigations, and interpret data based on evidence (OECD, 2023). One of the environmental issues that is highly relevant in urban communities is flooding.

Urban flooding is influenced by various factors, including climate change, rapid urban development, reduced green areas, inadequate drainage systems, and human behavior such as improper waste disposal (Pauleit, 2019). Therefore, environmental education related to flood mitigation needs to be introduced from elementary school. In the context of the Merdeka Curriculum in Indonesia, IPAS learning is designed to integrate natural and social sciences to help students understand relationships between humans, nature, and environmental phenomena (Solehayati et al., 2026). However, classroom implementation often remains focused on textbook-based learning and conceptual memorization. Students may know definitions and causes of flooding but experience difficulties connecting scientific concepts with actual environmental problems.

This condition indicates the need for learning approaches that actively involve students in constructing knowledge. Inquiry-based learning is considered appropriate because it encourages students to investigate problems, formulate questions, collect information, analyze evidence, and develop conclusions (Aksa, 2022). Through inquiry activities, students experience scientific processes similar to real scientific investigations (Muhamad Dah et al., 2024). In addition, technological development provides opportunities to improve science learning through digital media (Henita et al., 2025). Digital simulations allow students to visualize complex phenomena that cannot always be observed directly in classrooms. In flood-related learning, simulations can demonstrate rainfall processes, water flow, land-use changes, and the consequences of environmental behaviors (Widya Murni et al., 2026). The combination of inquiry learning and digital simulation has the potential to create meaningful, contextual, and technology-supported IPAS learning. Students not only acquire scientific knowledge but also develop environmental responsibility through understanding the relationship between human actions and natural phenomena.

Previous studies have shown that inquiry-based learning contributes positively to students' scientific reasoning and conceptual understanding (Farhan Iqbal Pratama et al., 2026). However, several gaps remain (Simatupang, 2026). First, many studies on inquiry learning focus mainly on science achievement outcomes, while the connection between inquiry learning and environmental behavior development, particularly disaster mitigation behavior, remains less explored. Second, digital simulation research in elementary education has often emphasized motivation and conceptual understanding rather than its contribution to strengthening students' scientific literacy and environmental decision-making(Wijayanti et al., 2025). Third, urban flood issues represent authentic environmental challenges, yet limited research has examined how IPAS learning using inquiry and digital simulation approaches can prepare elementary students to understand and respond to flood risks (Rahmayati & Prastowo, 2023). Therefore, this study addresses these gaps by integrating inquiry learning and digital simulation within IPAS instruction to strengthen both scientific literacy and flood mitigation behavior.

This study aims to analyze the implementation of inquiry-based and digital simulation-assisted IPAS learning in elementary schools (Dewi et al., 2023). The analysis focuses on how inquiry-based learning and digital simulations are integrated into the learning process, including students' engagement in identifying problems, conducting investigations, interpreting information,

discussing findings, and formulating solutions related to environmental issues, particularly floods (Tias et al., 2026). In addition, the study examines the role of digital simulations in providing students with interactive and contextual learning experiences that enable them to visualize flood-related phenomena and explore possible mitigation strategies in a safe and engaging learning environment.

Furthermore, this study aims to examine the improvement of students' science literacy after participating in inquiry-based and digital simulation-assisted learning (Muhamad Dah et al., 2024). Science literacy is examined through students' ability to explain scientific phenomena, evaluate and design scientific inquiry, and interpret data and evidence scientifically. The study compares students' learning outcomes before and after the intervention to determine the extent to which the learning approach supports the development of students' scientific knowledge, inquiry skills, reasoning abilities, and capacity to use scientific evidence in understanding environmental problems.

Finally, this study investigates changes in students' flood mitigation behavior following the learning intervention. The investigation focuses on students' awareness, attitudes, preparedness, and ability to apply appropriate mitigation actions before, during, and after flood events. Through inquiry activities and digital simulations, students are expected to develop a stronger understanding of flood risks and become more capable of making informed decisions and demonstrating responsible behavior in responding to flood hazards. Thus, the study seeks to determine whether the learning intervention contributes not only to improvements in science literacy but also to the development of students' practical preparedness and environmentally responsible behavior.

RESEARCH METHODOLOGY

This study employed a quantitative approach using a quasi-experimental research design. The quasi-experimental approach was selected because it allows researchers to examine the effectiveness of educational interventions in real classroom settings where random assignment is difficult to implement (Creswell & Creswell, 2023). Instruments included science literacy tests, flood mitigation behavior questionnaires, observation sheets, and documentation. Data were analyzed using descriptive statistics and normalized gain analysis. This study employed a quantitative approach using a quasi-experimental method. The research design used was a **one-group pretest-posttest design**.

The research design can be described as:

$$\mathbf{O_1 \rightarrow X \rightarrow O_2}$$

Where:

O_1 = students' initial science literacy and mitigation behavior (pretest)

X = inquiry-based IPAS learning integrated with digital simulation

O_2 = students' science literacy and mitigation behavior after intervention (posttest)

Where O_1 represents the pretest measurement, X represents the inquiry-based and digital simulation-assisted IPAS learning intervention, and O_2 represents the posttest measurement. The learning intervention was developed based on the inquiry learning cycle, consisting of orientation, questioning, investigation, data analysis, and conclusion development. Inquiry-based learning emphasizes students' active involvement in constructing knowledge through scientific investigation processes (Pedaste et al., 2015). Digital simulations were integrated into learning activities to support students' understanding of flood phenomena. Multimedia-based learning principles suggest that combining visual and verbal representations can improve students' comprehension of complex scientific concepts (Mayer, 2021).

The research instruments consisted of a science literacy test, flood mitigation behavior questionnaire, and observation sheets. The science literacy test was developed based on the OECD science literacy framework, which includes explaining scientific phenomena, evaluating investigations, and interpreting evidence (OECD, 2023). Instrument validity was evaluated through expert judgment using Aiken's V analysis, while reliability was measured using Cronbach's Alpha coefficient. Valid and reliable instruments are essential to ensure accurate measurement of educational outcomes (Sugiyono, 2022). Data analysis involved descriptive statistics and normalized gain (N-Gain) analysis to determine students' improvement after the intervention. The N-Gain method is commonly used in educational research to measure learning effectiveness based on pretest and posttest improvement. The participants were fifth-grade elementary school students from an urban elementary school. The selection of fifth-grade students was based on their developmental readiness to engage in scientific inquiry activities and understand environmental phenomena. The intervention was conducted through inquiry-based IPAS learning integrated with digital flood simulations.

Validity and Reliability of Research Instruments

The validity and reliability of the research instruments were examined to ensure that the instruments accurately measured students' science literacy and flood mitigation behavior. The instruments used in this study consisted of a science literacy test, a flood mitigation behavior questionnaire, and observation sheets during the inquiry-based and digital simulation-assisted IPAS learning process. Content validity was conducted through expert judgment involving experts in science education and elementary education. The experts evaluated the relevance, clarity, and suitability of each instrument item based on the research objectives, science literacy indicators, and learning outcomes of IPAS. The validation process focused on ensuring that the instruments represented the aspects being measured, including students' ability to explain scientific phenomena, interpret evidence, analyze environmental problems, and demonstrate flood mitigation awareness.

The results of expert validation indicated that the instruments were appropriate for use after several revisions related to language clarity, item construction, and alignment with the indicators of science literacy and environmental behavior. The revised instruments were then tested on students with similar characteristics to the research participants to determine their empirical quality. The results confirm that the developed instruments were appropriate for data collection and capable of measuring changes in students' science literacy and flood mitigation behavior after the implementation of inquiry-based learning integrated with digital simulation.

Table 1. Validity Instruments

Instrument	Validator	Aspect Evaluated	Result
Science Literacy Test	Science Education Experts	Content relevance, language clarity, scientific indicators	Valid
Flood Mitigation Questionnaire	Elementary Education Experts	Behavior indicators, item suitability	Valid
Observation Sheet	Learning Experts	Activity indicators and observation criteria	Valid

The validity of the research instruments was evaluated through expert judgment to ensure that the instruments were appropriate for measuring students' science literacy and flood mitigation behavior. Three experts in science education, elementary education, and educational assessment

were involved in the validation process. The validation focused on several aspects, including content relevance, construct suitability, language clarity, and alignment between instrument indicators and research objectives.

Table 2. Expert Validation Results of Research Instruments

Instrument	Aspect Evaluated	Number of Items	Aiken's V	Interpretation
Science Literacy Test Flood	Content relevance, scientific literacy indicators, item clarity	15	0.87	Very Valid
Mitigation Behavior Questionnaire	Environmental awareness, preventive behavior, disaster preparedness	20	0.89	Very Valid
Learning Observation Sheet	Learning activity indicators, student engagement, inquiry process	12	0.85	Very Valid

The validation results showed that all research instruments achieved a high level of validity. The science literacy test obtained an Aiken's V value of 0.87, indicating that the items were highly relevant to the science literacy indicators, including the ability to explain scientific phenomena, analyze evidence, and interpret environmental information. The flood mitigation behavior questionnaire obtained an Aiken's V value of 0.89, demonstrating that the questionnaire items appropriately represented students' environmental awareness, preventive actions, and disaster preparedness behavior.

Furthermore, the learning observation sheet obtained an Aiken's V value of 0.85, indicating that the observation indicators were suitable for assessing students' participation during inquiry-based and digital simulation-assisted IPAS learning activities. Based on the expert evaluation criteria, all instruments were categorized as very valid because the validity coefficients exceeded the minimum acceptance value of 0.80.

Instrument reliability was analyzed using Cronbach's Alpha coefficient to measure the internal consistency of the questionnaire and test items. An instrument is considered reliable when the Cronbach's Alpha value is ≥ 0.70, indicating that the items consistently measure the intended construct. The reliability analysis showed that the science literacy test and flood mitigation behavior questionnaire had acceptable reliability levels, indicating that the instruments were consistent and suitable for data collection.

Table 3. Reability

Instrument	Cronbach's Alpha	Interpretation	Instrument
Science Literacy Test	0.82	High Reliability	Science Literacy Test
Flood Mitigation Questionnaire	0.86	High Reliability	Flood Mitigation Questionnaire
Observation Sheet	0.79	Reliable	Observation Sheet

RESULT AND DISCUSSION

This Result is the implementation of inquiry-based IPAS learning integrated with digital simulation was conducted through a series of scientific learning activities. Students were actively involved in identifying flood problems, analyzing causes, interpreting simulation results, and developing mitigation strategies. During the learning process, students showed increased engagement through questioning, discussion, and collaborative investigation. The digital simulation

provided visual representations of flood processes, enabling students to understand the relationship between rainfall, land use, drainage systems, and human activities. The observation results indicated that students gradually shifted from passive learning behavior to active participation. Students were able to formulate questions, analyze environmental problems, and propose solutions based on scientific reasoning.

Meeting 1: Introduction to Flood Phenomena

The first meeting focused on introducing students to the phenomenon of urban flooding through inquiry-based learning supported by digital simulation. The learning activity was designed to build students' initial understanding of flood processes and encourage them to develop scientific questions based on real environmental problems (Wen et al., 2020). At this stage, students were introduced to flooding as a contextual issue that frequently occurs in urban areas and is closely related to environmental conditions and human activities.

The learning process began with the teacher presenting flood-related videos and interactive digital simulations illustrating the occurrence of flooding, including heavy rainfall, water accumulation, drainage problems, and changes in land use. Students were asked to observe the digital representations carefully and identify important information related to the causes, processes, and impacts of flooding. Through this activity, students were encouraged to connect the observed phenomena with their previous experiences and knowledge about floods in their surrounding environment.



Figure 1. Introduction to Flood Phenomena

After observing the videos and simulations, students worked collaboratively in small groups to analyze the factors contributing to flooding. Students discussed both natural and human factors, such as high rainfall intensity, river overflow, inadequate drainage systems, waste accumulation, and reduced green areas due to urban development. The discussion activity was designed to develop students' ability to explain environmental phenomena scientifically and recognize the relationship between human behavior and environmental changes.

Meeting 2: Investigation and Analysis

The second meeting focused on developing students' scientific investigation skills through the analysis of factors contributing to urban flooding. This activity was designed to strengthen students' science literacy by encouraging them to examine evidence, identify causal relationships, and construct scientific explanations based on the flood phenomenon introduced in the previous meeting. The learning activity began with students reviewing the flood phenomena observed through videos and digital simulations (Wen et al., 2020). Students worked collaboratively in groups to investigate the main factors influencing flooding, including rainfall intensity, drainage system conditions, land surface changes, and human environmental behavior. Through guided inquiry activities, students were encouraged to analyze how each factor contributes to the occurrence and severity of flooding in urban areas.



Figure 2. Students' scientific investigation skills

During the investigation process, students analyzed the role of rainfall factors by examining how high rainfall intensity and prolonged rain duration can increase surface water accumulation. Students discussed the relationship between rainfall patterns and the capacity of urban drainage systems to manage water flow. Furthermore, students investigated drainage systems through digital simulations that demonstrated differences between effective and ineffective water management systems. The simulation showed how blocked drainage channels, limited water absorption areas, and inadequate drainage capacity can increase flood risks. Students interpreted the simulation results and discussed possible solutions to improve water flow management.

The investigation also emphasized the influence of human environmental behavior on flood occurrence (Fitria, 2013). Students analyzed how activities such as improper waste disposal, excessive construction, and reduction of green spaces can affect water absorption and increase surface runoff. Through discussion, students developed an understanding that flooding is not only caused by natural factors but is also influenced by human interactions with the environment. Digital simulations were used as an interactive learning tool to visualize changes in land surfaces and their impact on flooding. Students observed different scenarios, such as areas with more vegetation compared to areas dominated by buildings and concrete surfaces. They analyzed how land-use changes affect water infiltration and runoff processes.

During this activity, the teacher acted as a facilitator by guiding students through scientific reasoning processes and encouraging them to support their explanations with evidence from

observations (Wen et al., 2020). Students recorded their findings, compared different simulation scenarios, and developed conclusions based on the investigation results.

Through Meeting 2, students developed important components of science literacy, including analyzing scientific information, interpreting evidence, identifying cause-and-effect relationships, and proposing environmentally responsible solutions. The integration of inquiry activities and digital simulations provided students with opportunities to understand flood phenomena through active investigation rather than passive knowledge acquisition.

Meeting 3: Solution Development

The third meeting focused on developing students' ability to propose scientific and practical solutions for flood mitigation based on the investigation results obtained in the previous learning activities. This stage represented the final phase of the inquiry-based learning process, where students were encouraged to apply their scientific understanding to address real environmental problems (Wen et al., 2020). Through collaborative activities, students transformed their findings about flood causes and impacts into action-oriented mitigation strategies. The learning activity began with students reviewing the results of their investigations regarding rainfall factors, drainage conditions, land surface changes, and human environmental behaviors that contribute to flooding. Students discussed the relationship between environmental problems and possible solutions by using evidence obtained from digital simulations and group observations. The teacher guided students to evaluate whether the proposed solutions were realistic, environmentally sustainable, and applicable in their daily lives.

In this activity, students worked in groups to develop flood mitigation solutions through several approaches. The first approach was designing environmental campaigns. Students created ideas for campaigns aimed at increasing environmental awareness among the school community, such as posters, digital messages, and classroom campaigns about maintaining cleanliness, protecting water channels, and reducing behaviors that contribute to flooding. Through this activity, students learned how scientific knowledge can be communicated to influence community behavior.



Figure 3. Students' develop flood mitigation solutions

The second activity involved developing waste management strategies. Students analyzed how improper waste disposal can block drainage systems and increase flood risks. Based on their understanding, students proposed strategies such as waste separation, recycling activities, reducing plastic waste, and encouraging responsible waste disposal habits. This activity helped students

understand that individual actions have an important role in preventing environmental problems. The third activity focused on creating school-based flood prevention actions. Students discussed possible actions that could be implemented in the school environment, including maintaining drainage areas, increasing green spaces, conserving water, and developing preparedness plans during flood events. Students were encouraged to design simple action plans that could involve teachers, classmates, and the wider school community. During the solution development process, students presented their ideas through group presentations and received feedback from classmates and the teacher. The discussion encouraged students to evaluate different solutions and improve their proposals based on scientific reasoning. The teacher acted as a facilitator by guiding students to ensure that their solutions were connected with the concepts of environmental science and flood mitigation.

This activity strengthened students' science literacy by requiring them to use scientific knowledge to solve authentic problems. Students not only understood the causes and impacts of flooding but also developed the ability to make evidence-based decisions and demonstrate environmental responsibility. The integration of inquiry learning and digital simulation supported students in moving from understanding scientific phenomena toward applying knowledge in real-world contexts.

Overall, Meeting 3 demonstrated that inquiry-based and digital simulation-assisted IPAS learning can support the development of students' problem-solving skills, environmental awareness, and flood mitigation behavior. By engaging students in solution development activities, learning became more meaningful because students were positioned as active contributors in addressing environmental challenges.

Improvement of Students' Science Literacy

The improvement of students' science literacy was measured by comparing students' performance before and after the implementation of inquiry-based and digital simulation-assisted IPAS learning (Mediana et al., 2025). The measurement was conducted using a science literacy test developed based on three main indicators: (1) explaining scientific phenomena, (2) analyzing and evaluating scientific information, and (3) interpreting evidence related to environmental issues, particularly urban flooding. The pretest was administered before the learning intervention to identify students' initial understanding of flood phenomena and their ability to use scientific concepts in explaining environmental problems. The improvement indicates that the learning model successfully supported students in constructing scientific knowledge through active investigation. During the inquiry activities, students were not only exposed to information about flooding but were also involved in identifying problems, analyzing evidence, and developing explanations based on observed phenomena. The integration of digital simulation contributed to students' conceptual understanding by providing visual representations of complex flood processes. Through simulation activities, students were able to observe the relationship between rainfall intensity, drainage conditions, land surface changes, and human activities. This visualization helped students understand abstract environmental concepts that are difficult to observe directly in classroom settings. Furthermore, students showed improvement in their ability to explain flood phenomena scientifically. Before the intervention, many students described flooding mainly based on everyday experiences, such as "too much rain" or "water overflowing." After participating in inquiry and simulation activities, students were able to provide more scientific explanations by relating flooding to environmental factors such as reduced water absorption areas, blocked drainage systems, and changes in land use. The findings indicate that inquiry-based and digital simulation-assisted IPAS

learning effectively promotes the development of science literacy among elementary school students. The learning approach provides opportunities for students to engage in scientific practices, interpret evidence, and apply scientific knowledge to real-world environmental issues.

The posttest was conducted after the completion of the inquiry-based learning activities and digital simulation experiences to determine the improvement of students' scientific understanding. The results presented in Table 3 show an increase in students' science literacy scores after participating in the learning intervention. The average pretest score was 61.25, while the average posttest score increased to 84.60. The improvement of 23.35 points indicates that students developed better understanding and reasoning abilities after experiencing inquiry-based learning supported by digital simulations. The improvement of students' science literacy was measured through pretest and posttest scores.

Table 3. Science Literacy Score Improvement

Measurement	Mean Score	Standard Deviation
Pretest	61.25	8.42
Posttest	84.60	7.15
Improvement	**23.35**	**-**

These results are consistent with the principles of science education proposed by the National Research Council (2012), which emphasizes that effective science learning should involve students in scientific practices, including questioning, investigation, evidence analysis, and explanation development. Therefore, the integration of inquiry learning and digital simulation can be considered an effective strategy for strengthening science literacy in elementary environmental education.

N-Gain Analysis of Students' Science Literacy Improvement

To further analyze the effectiveness of inquiry-based and digital simulation-assisted IPAS learning, the improvement of students' science literacy was calculated using the normalized gain (N-Gain) analysis. The N-Gain analysis was used to determine the level of improvement between students' pretest and posttest scores across three science literacy indicators: explaining scientific phenomena, scientific investigation ability, and evidence interpretation. The results in Table 4 indicate that students experienced a high level of improvement in science literacy after participating in inquiry-based and digital simulation-assisted IPAS learning. The overall average N-Gain score was 0.71, which is categorized as high, demonstrating that the learning intervention effectively enhanced students' ability to understand and apply scientific concepts related to flood phenomena.

Among the three indicators, the highest improvement was found in the evidence interpretation ability, with an N-Gain score of 0.74.

The results of the N-Gain analysis are presented in Table 4. This finding indicates that students became more capable of analyzing information obtained from observations, simulations, and discussions. Through digital simulation activities, students were able to examine relationships between rainfall intensity, drainage conditions, land surface changes, and flood occurrence. The visual representation provided by the simulation helped students interpret scientific evidence more effectively and develop logical explanations.

Table 4. N-Gain Analysis of Science Literacy

Indicator	N-Gain Score	Category
Explaining scientific phenomena	0.71	High
Scientific investigation ability	0.68	Medium

Evidence interpretation	0.74	High
Average	0.71	High

The indicator of explaining scientific phenomena also showed a high improvement level, with an N-Gain score of 0.71. This result suggests that students improved their ability to describe flooding using scientific concepts rather than relying only on personal experiences. After participating in inquiry activities, students were able to explain that flooding is influenced by multiple factors, including environmental changes, human activities, and water management systems.

Meanwhile, the scientific investigation ability indicator obtained an N-Gain score of 0.68, categorized as medium. Although the improvement was slightly lower than the other indicators, the result still demonstrates positive development in students' inquiry skills. Students gradually improved their ability to identify problems, formulate questions, collect information, and analyze findings. The medium category may be related to the fact that scientific investigation skills require continuous practice and longer learning experiences to develop optimally.

The findings demonstrate that the combination of inquiry learning and digital simulation provides meaningful opportunities for students to engage in scientific practices. Inquiry activities encourage students to actively investigate environmental problems, while digital simulations support deeper understanding by providing concrete representations of complex phenomena. This result supports the view of the National Research Council (2012) that science learning should involve students in scientific practices, including questioning, investigating, analyzing evidence, and constructing explanations.

Therefore, the implementation of inquiry-based and digital simulation-assisted IPAS learning can be considered an effective approach to strengthening elementary students' science literacy, particularly in understanding environmental phenomena such as urban flooding.

Improvement of Flood Mitigation Behavior

In addition to science literacy, the study examined changes in students' flood mitigation behavior after the learning intervention. The behavior assessment focused on environmental awareness, preventive actions, and disaster preparedness.

Table 5. Flood Mitigation Behavior Improvement

Measurement	Mean Score
Pre-intervention	67.40
Post-intervention	86.75
Improvement	**19.35**

The results indicate that students demonstrated improved awareness and responsibility toward flood prevention. After participating in inquiry and simulation activities, students showed better understanding of how human behaviors influence environmental conditions. Students began to recognize that simple actions, such as proper waste disposal, maintaining drainage systems, and protecting green areas, contribute to reducing flood risks. The learning activities encouraged students to move from understanding environmental problems toward taking preventive actions. This finding demonstrates that science learning can contribute not only to cognitive development but also to the formation of environmentally responsible behavior. By connecting scientific concepts with real-life problems, students gained meaningful experiences that supported environmental decision-making.

The findings of this study demonstrate that inquiry-based and digital simulation-assisted IPAS learning provides significant benefits in improving students' science literacy and flood mitigation behavior. The learning model successfully combines scientific investigation with technology-supported visualization, allowing students to understand environmental phenomena more deeply. Inquiry learning encourages students to become active learners who investigate problems, analyze evidence, and develop solutions. This approach aligns with constructivist learning theory, which emphasizes that knowledge is actively constructed through meaningful experiences. The use of digital simulation strengthens the learning process by providing visual and interactive representations of flood phenomena. Students can observe processes that are difficult to demonstrate directly, such as changes in water flow caused by land-use transformation and drainage limitations. Furthermore, the integration of environmental issues into IPAS learning creates contextual learning experiences. Students understand that science is connected to everyday life and that scientific knowledge can be used to solve real-world problems. This contributes to the development of both science literacy and environmental responsibility. Overall, the results indicate that inquiry-based learning integrated with digital simulation is an effective strategy for elementary science education, particularly for teaching environmental topics such as flood mitigation. The approach supports students in developing scientific understanding, critical thinking, problem-solving skills, and responsible environmental behaviors.

The findings of this study indicate that inquiry-based and digital simulation-assisted IPAS learning effectively improves students' science literacy and environmental awareness. The improvement occurred because students were actively engaged in scientific practices, including observing phenomena, formulating questions, investigating evidence, and developing explanations. Inquiry-based learning provides opportunities for students to construct scientific knowledge through meaningful investigation processes rather than receiving information passively. Previous research has also demonstrated that inquiry-based learning is associated with the development of science literacy when supported by appropriate instructional quality and learning design (Kang, 2022).

The improvement in evidence interpretation is supported by the use of digital simulations. Simulation technology provides interactive representations that allow students to explore relationships between variables, such as rainfall intensity, drainage capacity, and land-use changes. Previous research found that simulation-supported inquiry learning improves students' scientific literacy because learners can actively explore scientific phenomena and interpret evidence (Cai et al., 2020).

The ability to explain scientific phenomena also showed high improvement (**0.71**). Students were able to move from simple descriptions of flooding toward scientific explanations involving environmental factors and human activities. This finding supports OECD's (2023) framework that scientific literacy involves applying knowledge to explain real-world phenomena. In addition to cognitive improvement, students demonstrated better flood mitigation behavior. Through activities such as environmental campaigns, waste management strategies, and school-based prevention actions, students developed awareness that human behavior influences environmental conditions. Environmental education that connects scientific knowledge with authentic problems can encourage responsible environmental actions (UNESCO, 2021).

The findings indicate that inquiry-based and digital simulation-assisted IPAS learning provides a meaningful learning environment where students develop both scientific competence and environmental responsibility. This supports previous research showing that technology-supported inquiry learning enhances higher-order thinking skills and scientific understanding (Antonio & Prudente, 2024).

In this Discussion An important factor that may explain the improvement is the continuity between the learning activities across the three meetings. The learning process was not organized as separate activities, but as a progressive sequence in which the understanding developed in one meeting became the basis for the next activity. In the first meeting, students were introduced to flooding through videos and digital simulations and were encouraged to connect the phenomenon with their previous experiences. This initial engagement helped activate students' prior knowledge and created questions that could be investigated further. The second meeting then provided opportunities for students to test and develop their initial understanding through investigation. Students compared different conditions involving rainfall, drainage systems, land surfaces, and environmental behavior. By comparing these conditions, students could recognize that flood occurrence is associated with the interaction of several factors rather than a single cause. This comparison process was important because it encouraged students to move from simply identifying information toward identifying relationships between variables. The teacher's role as a facilitator also helped students connect the evidence obtained from the simulation with appropriate scientific explanations. Another possible explanation is the repeated opportunity to discuss and communicate scientific reasoning. During group activities, students were required to explain their observations to peers, compare interpretations, and defend their conclusions using evidence. Such interaction may have helped students clarify misconceptions because an explanation that was initially incomplete could be reconsidered through discussion and teacher feedback. Therefore, the improvement in science literacy may not only reflect individual interaction with the digital simulation but also the social process of constructing and negotiating meaning during collaborative inquiry. The article reports that students became increasingly engaged through questioning, discussion, and collaborative investigation.

The use of a familiar and authentic environmental issue may have further strengthened this learning process. Flooding is not presented as an abstract scientific phenomenon but as an environmental problem that students can recognize in an urban context. When students investigated drainage, waste accumulation, reduced green areas, and land-use changes, they could connect scientific concepts with situations that have practical consequences in their surroundings. This contextual connection may have increased the meaningfulness of the learning experience and encouraged students to apply scientific reasoning beyond the classroom. The learning activities subsequently required students to transform their understanding of flood causes into practical mitigation strategies, strengthening the connection between scientific knowledge and environmental decision-making. The improvement may also be related to the progressive movement from cognitive understanding toward action. Students first learned to recognize the phenomenon, then investigated its causes, and finally developed solutions. This progression allowed students to experience science not simply as a body of knowledge but as a process for understanding and responding to real-world problems. In particular, the third meeting required students to evaluate whether proposed mitigation actions were realistic, environmentally sustainable, and applicable to their daily lives. Such activities provided a bridge between science literacy and environmental responsibility. The role of the teacher as a facilitator is also important in explaining the observed improvement. Although inquiry learning emphasizes student activity, the students in this study were not left to investigate the phenomenon without direction. The teacher guided students in formulating questions, interpreting simulation results, comparing evidence, and evaluating proposed solutions. This guided structure may have helped elementary students manage the cognitive demands of inquiry while still allowing them to construct their own understanding. Therefore, the findings

suggest that the combination of student autonomy and appropriate teacher scaffolding, rather than inquiry activity alone, contributed to the development of students' science literacy.

Furthermore, the digital simulation provided an opportunity for students to revisit the same phenomenon under different conditions. Instead of observing flooding only as a single event, students could examine how changes in environmental conditions influenced water accumulation and flood risk. This repeated examination potentially strengthened students' understanding of causal relationships because they could compare scenarios and identify patterns. Such an experience is particularly relevant for elementary students, for whom direct observation of complex environmental processes may be limited. The simulation therefore served as a bridge between an observable environmental problem and scientific concepts that are otherwise difficult to demonstrate directly in the classroom. Importantly, the findings suggest that the strength of the intervention lies in the integration of inquiry and simulation rather than in either component separately. Inquiry without adequate representation of complex processes may make it difficult for elementary students to visualize relationships among environmental variables, whereas simulation without inquiry may reduce learning to passive observation. In the present learning design, simulation provided the evidence and visual representation, while inquiry provided the questions, analytical processes, and decision-making structure through which students interpreted that evidence. This complementary relationship offers a plausible explanation for the relatively high overall N-Gain of 0.71 and the particularly strong improvement in evidence interpretation (0.74).

Finally, the findings indicate that learning about disaster mitigation may be more meaningful when students are positioned as problem solvers rather than merely recipients of disaster information. In the third meeting, students were asked to develop environmental campaigns, waste-management strategies, and school-based flood-prevention actions. These activities required them to consider how scientific knowledge could be translated into concrete actions. Consequently, the learning experience potentially strengthened students' perception that their own behavior can influence environmental conditions. This provides a reasonable explanation for the increase in the flood mitigation behavior score from 67.40 to 86.75.

Taken together, these findings suggest that the observed improvement was supported by a coherent learning mechanism in which authentic environmental problems stimulated inquiry, digital simulations provided accessible scientific evidence, collaborative discussion facilitated meaning-making, teacher scaffolding supported investigation, and solution-development activities connected scientific understanding with environmental action. The combination of these elements created a learning experience in which students could progressively move from observing a problem to explaining its causes, interpreting evidence, and proposing appropriate solutions. Thus, the contribution of the learning model lies not simply in introducing digital technology into IPAS instruction, but in using technology as an integral component of an inquiry process that connects scientific literacy with real-world environmental responsibility.

CONCLUSION

This study concludes that inquiry-based and digital simulation-assisted IPAS learning is an effective approach for strengthening science literacy and flood mitigation behavior among elementary school students. The integration of inquiry activities encourages students to engage in scientific practices, including questioning, investigation, evidence analysis, and explanation development (National Research Council, 2012). The use of digital simulation enhances students' understanding by providing interactive representations of flood phenomena that support conceptual development and scientific reasoning (Mayer, 2021). The improvement in science literacy scores

and N-Gain results demonstrates that students developed stronger abilities in explaining phenomena, interpreting evidence, and applying scientific knowledge to environmental problems.

The findings demonstrate that students' science literacy improved significantly after participating in the learning intervention(Wen et al., 2020). The increase in posttest scores and the N-Gain analysis indicate that students developed better abilities in explaining scientific phenomena, conducting scientific investigations, and interpreting evidence related to flood events. The high average N-Gain score (0.71) confirms that inquiry-based learning supported by digital simulation is effective in improving students' understanding of environmental science concepts.

Furthermore, the learning model also contributed to the improvement of students' flood mitigation behavior. Through contextual activities such as analyzing flood causes, designing environmental campaigns, developing waste management strategies, and proposing school-based prevention actions, students developed greater awareness of the relationship between human behavior and environmental sustainability.

The combination of inquiry learning and digital simulation enables students to move beyond conceptual understanding toward the application of scientific knowledge in real-life situations. Students are encouraged to become active problem solvers who can use scientific evidence to make responsible decisions regarding environmental issues.

Therefore, inquiry-based and digital simulation-assisted IPAS learning can be recommended as an innovative approach for elementary science education, particularly in teaching environmental topics and disaster mitigation. Future studies are suggested to explore this learning model with larger samples, different educational contexts, and longer implementation periods to examine its long-term impact on students' scientific literacy and environmental behavior.

DECLARATION OF AI AND AI ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this manuscript, the authors used artificial intelligence (AI) and AI-assisted technologies as supporting tools in the writing process, particularly for improving language organization, enhancing academic expression, and assisting in the development of the manuscript structure. AI tools were used to support the refinement of ideas, improve readability, and assist in the preparation of sections according to academic writing standards.

The authors confirm that all research ideas, methodology, data analysis, interpretations, and scientific conclusions presented in this manuscript are the authors' original work and responsibility. AI-assisted tools were not used to replace the authors' critical thinking, scientific judgment, or the process of generating research findings.

The authors have carefully reviewed, revised, and verified all content generated with AI assistance to ensure accuracy, academic integrity, and compliance with ethical publication standards. The authors take full responsibility for the final content, including the accuracy of information, citations, and conclusions presented in this article.

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AUTHORS' CONTRIBUTION

Author 1: Conceptualization; Project administration; Writing - original draft
Author 2: Methodology; Data curation; Proofreading; Writing - review and editing.
Author 3: Formal analysis. In-vestigation; Retrieving data

DECLARATION OF COMPETING INTEREST

The authors declare that there are no competing interests, including financial, professional, or personal relationships, that could have influenced the research process, data analysis, interpretation of results, or preparation of this manuscript. The authors confirm that this research was conducted independently and objectively. All decisions related to the study design, implementation, analysis, and reporting were based on academic and scientific considerations. The authors have no affiliations or relationships with any organization or entity that may have a financial or non-financial interest in the outcomes of this research. Dr. Sulistyani Puteri Ramadhani, M.Pd. and Dr. Rudi Ritonga, M.Pd. declare that this manuscript represents original work and has not been influenced by any external interests that could affect the integrity and credibility of the research findings.

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