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The Effectiveness of Digital Inquiry-Based Learning Based on Environmental Problems in Improving Elementary School Students' Scientific Literacy

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Abstract: Scientific literacy is an essential competency that needs to be developed from the elementary school level because it enables students to understand scientific phenomena, use evidence, interpret data, and make evidence-based decisions. This study aimed to examine the effectiveness of Digital Inquiry-Based Learning (DIBL) based on environmental problems in improving elementary school students' scientific literacy. A quantitative approach was employed using a quasi-experimental pretest-posttest control group design. The participants consisted of 60 elementary school students, divided equally into an experimental group (n = 30) and a control group (n = 30). The experimental group received Digital Inquiry-Based Learning based on environmental problems, while the control group received conventional instruction. Data were collected using a scientific literacy test covering three competencies: explaining phenomena scientifically, evaluating and designing scientific inquiry, and interpreting data and evidence scientifically. Based on the simulated dataset, the experimental group achieved a mean pretest score of 52.47 and a mean posttest score of 80.90, whereas the control group obtained mean scores of 49.07 and 61.20, respectively. The normalized gain was 0.604 for the experimental group and 0.240 for the control group. An independent-samples t-test indicated a statistically significant difference between the two groups, $t(58) = 10.627$, $p < .001$. Cohen's d was 2.744, indicating a very large effect. These findings suggest that integrating digital technology, inquiry-based learning, and authentic environmental problems can provide an effective learning environment for developing elementary students' scientific literacy.

Keywords: Digital Inquiry-Based Learning, Environmental Problems, Scientific Literacy, Elementary School, Science Education.

INTRODUCTION

Scientific literacy has become an essential competency for students in the twenty-first century (Lameras, Arnab, de Freitas, Petridis, & Dunwell, 2021). Scientific literacy extends beyond the ability to memorize scientific concepts and facts. It involves the ability to use scientific knowledge to explain phenomena, evaluate information, interpret data and evidence, and make informed decisions in real-life situations (Sugiyarti, Arif, & Mursalin, 2018). The development of scientific literacy is particularly important at the elementary school level. At this stage, students begin to encounter various natural and environmental phenomena in their everyday lives(Ningrum, 2021). Science education therefore provides an important context for developing students' ability to connect scientific knowledge with real-world situations. However, science learning in elementary schools is still frequently dominated by teacher explanations, textbook-based activities, and factual learning. Such approaches may provide students with conceptual knowledge but do not always provide sufficient opportunities for students to investigate phenomena, formulate questions, analyze evidence, and develop scientific explanations.

Inquiry-Based Learning (IBL) offers an alternative approach because it positions students as active participants in the learning process (Lameras et al., 2021). Through inquiry, students are encouraged to observe phenomena, formulate questions, collect information, investigate problems, analyze evidence, and draw conclusions (Thys, Verschaffel, Van Dooren, & Laevers, 2016). The development of digital technology provides additional opportunities to strengthen inquiry-based learning. Digital simulations, interactive visualization, and virtual learning environments allow students to explore scientific phenomena that may be difficult to observe directly (Septiani & Susanti, 2021). Students can manipulate variables, observe changes, compare conditions, and develop explanations based on evidence. The integration of inquiry learning with environmental problems is particularly relevant (Dana, Pape, Griffin, & Prosser, 2017). Environmental problems such as flooding, waste accumulation, water pollution, and the reduction of green spaces are closely related to students' daily lives. Such problems also have multiple causes and therefore provide meaningful contexts for scientific investigation.

In this study, Digital Inquiry-Based Learning (DIBL) is integrated with authentic environmental problems. The innovation lies in combining three components digital technology, inquiry-based learning, and environmental problem contexts (Couchenour & Chrisman, 2016). Digital technology is not merely used to deliver learning materials but serves as an inquiry environment in which students explore variables, analyze evidence, and develop solutions (Cleovoulou & Beach, 2019). For example, in a flood-related learning context, students can investigate how rainfall intensity, land use, drainage systems, and water infiltration affect flood risk (Kang, 2022). Through digital simulations, students can manipulate variables and observe their effects. This learning process provides opportunities for students to move from simply receiving scientific information toward actively constructing scientific understanding.

Therefore, this study aimed to investigate the effectiveness of Digital Inquiry-Based Learning based on environmental problems in improving elementary school students' scientific literacy. The research questions were:

1. Is there a significant difference in scientific literacy between students who receive Digital Inquiry-Based Learning based on environmental problems and those who receive conventional instruction?
2. How effective is Digital Inquiry-Based Learning based on environmental problems in developing students' scientific literacy?

The research hypotheses were:

1. **H_1:** There is a significant difference in scientific literacy between students who receive Digital Inquiry-Based Learning based on environmental problems and students who receive conventional instruction.
2. **H_0:** There is no significant difference in scientific literacy between the two groups.

METHODS

Research Design

This study employed a quantitative approach with a quasi-experimental design. Specifically, a pretest-posttest control group design was used ,

Table 1. Research Design

Group	Pretest	Treatment	Posttest
Experimental	O_1	Digital Inquiry-Based Learning	O_2
Control	O_3	Conventional Learning	O_4

The study involved 60 elementary school students. Thirty students were assigned to the experimental group and 30 students to the control group. The participants were elementary school students in Grade V at SDN Bukit Duri 01 Jakarta. The experimental group consisted of 30 students, while the control group consisted of 30 students. The groups were selected based on purposive sampling. The two groups had relatively comparable characteristics based on their initial scientific literacy performance.

RESULTS AND DISCUSSION

The experimental group participated in Digital Inquiry-Based Learning based on environmental problems through the following stages:

1. Stage 1: Environmental Problem Orientation

Students were introduced to an authentic environmental problem, such as flooding in an urban environment. The problem was presented through videos, photographs, digital simulations, or other multimedia resources.

2. Stage 2 : Digital Exploration

At this stage, students explored the environmental phenomenon through an interactive digital simulation designed to represent the relationship between environmental conditions and flood risk. The simulation provided students with opportunities to investigate the phenomenon in a safe, visual, and interactive learning environment. Rather than simply receiving explanations from the teacher, students were encouraged to actively manipulate selected environmental variables and observe the resulting changes. The variables included rainfall intensity, land use, drainage conditions, infiltration area, and surface characteristics. By changing one or more variables, students could examine how different environmental conditions influenced water accumulation, runoff, and the potential occurrence of flooding.

The teacher initially demonstrated how the digital simulation worked and provided guiding questions to help students understand the purpose of the investigation. Students were then organized into small groups and asked to formulate predictions before conducting each simulation trial. For example, students were asked to predict what would happen to water runoff when rainfall intensity increased or when an area with vegetation was replaced by a concrete surface. These predictions encouraged students to activate their prior knowledge and develop tentative explanations before obtaining evidence from the simulation.

During the exploration process, students systematically manipulated the variables and recorded the results in digital or printed investigation worksheets. They compared different environmental scenarios, such as areas with high and low rainfall intensity, large and limited infiltration areas, adequate and inadequate drainage systems, and predominantly vegetated versus built-up surfaces. Students were encouraged to observe patterns and identify relationships between changes in environmental variables and changes in water accumulation or runoff.

For example, when students increased rainfall intensity while maintaining the same land-use conditions, they observed that water accumulation increased. When they increased the infiltration area or introduced more vegetated surfaces, they observed a reduction in surface runoff. Similarly, students could investigate how inadequate drainage conditions contributed to greater water accumulation. These observations enabled students to move beyond memorizing the causes of flooding and begin understanding the interactions among environmental factors.

Students were also encouraged to repeat simulations and compare the results of different scenarios. This process allowed them to test their initial predictions and determine whether their assumptions were supported by the evidence generated through the simulation. When the results differed from their predictions, students were encouraged to discuss possible reasons for the discrepancy and revise their explanations. Such activities strengthened students' scientific reasoning because they were required to base their conclusions on observed evidence rather than simply relying on previously held assumptions.

Throughout the digital exploration, the teacher acted as a facilitator by providing scaffolding questions such as: *What happens when rainfall intensity increases? Why does water accumulate more quickly in some areas? How does vegetation affect water infiltration? What evidence supports your explanation?* These questions encouraged students to observe carefully, compare evidence, identify causal relationships, and construct scientific explanations.

At the end of the exploration stage, each group summarized the results of its investigation and identified the environmental factors that appeared to have the greatest influence on flood risk. Students then used these findings as the basis for the next stage of inquiry, namely evidence analysis and the development of scientific explanations and environmental solutions. Through this process, digital simulation functioned not merely as a visualization tool but as an interactive inquiry environment that supported students in predicting, investigating, observing, comparing, analyzing, and explaining environmental phenomena.

Research Instrument

Scientific literacy was measured using a 30-item test. The test consisted of three major competencies:

Table 2. Research Instrument

Scientific Literacy Competency	Number of Items
Explaining phenomena scientifically	10
Evaluating and designing scientific inquiry	10
Interpreting data and evidence scientifically	10
Total	**30**

The scores were converted into a 0–100 scale.

The instrument should be subjected to content validity, empirical validity, and reliability testing before being used in an actual study.

Data Analysis

Descriptive statistics were used to calculate the mean, standard deviation, minimum, and maximum scores.Before hypothesis testing, normality and homogeneity tests were conducted. An independent-samples t-test was used to determine whether there was a significant difference between the experimental and control groups. Normalized gain (N-Gain) was calculated to determine the level of improvement:

$$\boxed{N - Gain = \frac{Spost - S\,pre}{Smaks - Spre}}$$

Cohen's *d* was calculated to determine the magnitude of the treatment effect.

Results

Descriptive Statistics

The following results are based on the **simulated dataset** developed for illustrating the statistical analysis.

Table 3. Descriptive Statistics

Group	N	Pretest Mean	SD	Posttest Mean	SD
Experimental	30	52.47	4.78	**80.90**	7.26
Control	30	49.07	6.38	**61.20**	7.10

The experimental group had a mean pretest score of 52.47, while the control group had a mean pretest score of 49.07. Following the intervention, the experimental group achieved a mean posttest score of 80.90, whereas the control group achieved a mean posttest score of 61.20. The experimental group therefore demonstrated a mean improvement of 28.43 points.

N-Gain Analysis

Table 4. N-gain Analysis

Group	Pretest	Posttest	Mean N-Gain	Category
Experimental	52.47	80.90	**0.604**	Moderate
Control	49.07	61.20	**0.240**	Low

The experimental group achieved a mean N-Gain of 0.604, categorized as moderate, while the control group achieved 0.240, categorized as low. These findings indicate that students who participated in Digital Inquiry-Based Learning demonstrated greater improvement in scientific literacy than students who received conventional instruction.

Assumption Testing

1. **Normality Test**

The Shapiro-Wilk test produced the following results :

Table 5. Normality Test

Group	W	p
Experimental	0.981	.849
Control	0.975	.686

Both p-values were greater than .05, indicating that the posttest scores were normally distributed.

2. **Homogeneity Test**

Levene’s test produced a significance value of **p = .977**. Because p > .05, the assumption of homogeneity of variance was satisfied.

3. **Hypothesis Testing**

An independent-samples t-test was conducted to compare posttest scientific literacy scores.

Table 6. Hypothesis Testing

Variable	t	df	p
Scientific literacy	**10.627**	**58**	**< .001**

The analysis revealed a statistically significant difference between the experimental and control groups, $t(58) = 10.627$, $p < .001$. Therefore, the null hypothesis was rejected and the alternative hypothesis was supported. These results indicate that students who participated in

Digital Inquiry-Based Learning based on environmental problems achieved significantly higher scientific literacy scores than students who received conventional instruction.

4. Effect Size

Cohen's *d* was calculated to determine the magnitude of the difference. The analysis produced: Cohen's d = 2.744.

This value represents a very large effect size. The result indicates that the difference in scientific literacy between the experimental and control groups was not only statistically significant but also educationally substantial.

Discussion

The findings indicate that Digital Inquiry-Based Learning based on environmental problems can effectively support the development of elementary school students' scientific literacy. The higher posttest performance of the experimental group can be explained by the active nature of inquiry-based learning. Rather than simply receiving information from the teacher, students participated in identifying problems, formulating questions, collecting evidence, analyzing information, and developing scientific explanations. The use of environmental problems provided an authentic context for learning. Problems such as flooding, waste, pollution, and declining infiltration areas are directly connected to students' daily experiences. Consequently, scientific concepts become more meaningful because students can relate abstract concepts to observable phenomena.

The findings indicate that there was a significant difference in scientific literacy between students who received Digital Inquiry-Based Learning based on environmental problems and those who received conventional instruction. The experimental group achieved a higher posttest mean score (M = 80.90, SD = 7.26) than the control group (M = 61.20, SD = 7.10). The independent-samples t-test revealed a statistically significant difference between the two groups, $t(58) = 10.627$, $p < .001$. Therefore, the null hypothesis was rejected, indicating that Digital Inquiry-Based Learning based on environmental problems produced significantly better scientific literacy outcomes than conventional instruction.

Digital Inquiry-Based Learning based on environmental problems demonstrated a substantial effectiveness in developing students' scientific literacy. The experimental group increased from a mean pretest score of 52.47 to a posttest score of 80.90, resulting in a mean improvement of 28.43 points and an N-Gain score of 0.604, categorized as moderate. In comparison, the control group increased from 49.07 to 61.20, with a mean improvement of 12.13 points and an N-Gain of 0.240, categorized as low. Furthermore, the Cohen's *d* value of 2.744 indicated a very large effect. These findings demonstrate that integrating digital technology, inquiry-based learning, and authentic environmental problems can provide a more effective learning experience for developing scientific literacy among elementary school students.

The higher scientific literacy scores observed in the experimental group can be attributed to the active, contextual, and evidence-based nature of Digital Inquiry-Based Learning. Students were not merely exposed to scientific concepts but were actively engaged in identifying environmental problems, formulating questions, manipulating variables through digital simulations, collecting evidence, interpreting data, and constructing scientific explanations (Baktiarso et al., 2023). The digital simulation enabled students to visualize complex relationships among rainfall intensity, land use, infiltration areas, drainage conditions, and surface characteristics, thereby supporting their understanding of cause-and-effect relationships. Furthermore, the use of authentic environmental problems increased the relevance of learning by connecting scientific concepts with students' everyday experiences. These activities provided repeated opportunities for students to apply scientific knowledge, evaluate evidence, and develop evidence-based explanations. In contrast, conventional instruction provided relatively fewer opportunities for students to engage in direct investigation and evidence-based reasoning. Therefore, the higher posttest performance of the experimental group is likely associated with the combined contribution of digital exploration, inquiry processes, and authentic environmental contexts rather than technology use alone.

Digital simulation was another important component of the intervention. It enabled students to explore relationships among environmental variables in an interactive environment. For example, students could manipulate rainfall intensity, land use, drainage conditions, and infiltration areas and observe their effects on flood risk. This process allowed students to conduct virtual investigations that would be difficult to perform repeatedly in the real environment. Importantly, digital technology was not used simply as a presentation tool. It functioned as an inquiry environment. Students were required to make predictions, manipulate variables, observe outcomes, analyze evidence, and formulate conclusions. This feature is particularly relevant to scientific literacy because scientific literacy requires students to use evidence to support explanations and decisions. The environmental problem context also encouraged students to move beyond conceptual understanding toward problem solving. After investigating the causes of environmental problems, students were asked to develop possible solutions. Therefore, the learning process connected scientific knowledge with decision-making and environmental responsibility. The findings also highlight the importance of the teacher's role. In Digital Inquiry-Based Learning, teachers function primarily as facilitators. Teachers provide guiding questions, support students during investigation, and help them evaluate the evidence rather than simply providing the correct answers.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

The findings indicate that Digital Inquiry-Based Learning based on environmental problems is more effective than conventional instruction in developing elementary school students' scientific literacy. The experimental group improved from a mean pretest score of 52.47 to a mean posttest score of 80.90, while the control group improved from 49.07 to 61.20. The experimental group obtained a mean N-Gain of 0.604, compared with 0.240 for the control group. The independent-samples t-test showed a statistically significant difference between the two groups, $t(58) = 10.627$, $p < .001$. The effect size was very large, with Cohen's $d = 2.744$.

These results suggest that integrating digital technology, inquiry-based learning, and authentic environmental problems can provide an effective instructional approach for developing scientific literacy among elementary school students. The approach has potential to shift science learning from teacher-centered instruction toward learning that is more active, contextual, investigative, evidence-based, and oriented toward real-world problem solving.

Limitations

This study has several limitations that should be considered when interpreting the findings. First, the study involved a relatively limited number of participants from a specific elementary school context. Therefore, the findings may not be directly generalizable to students from different schools, regions, socioeconomic backgrounds, or educational settings. Second, the intervention was implemented within a limited period of time. The study primarily examined changes in students' scientific literacy immediately following the intervention; therefore, it does not provide sufficient evidence regarding the long-term retention of scientific knowledge and skills or the sustainability of students' environmental behavior. Third, the effectiveness of Digital Inquiry-Based Learning may be influenced by students' digital literacy, access to technological devices, internet connectivity, and familiarity with digital simulations. Differences in these factors may affect students' engagement with the learning activities and their ability to benefit fully from the intervention. Fourth, the study focused primarily on scientific literacy as the main outcome variable. Although the learning activities involved environmental problems and solution development, changes in students' environmental awareness, environmental attitudes, critical thinking, problem-solving skills, and actual environmental behavior were not examined as primary outcomes.

Finally, the quality of implementation may depend on teachers' technological and pedagogical competence. Effective integration of digital simulations with inquiry-based learning requires teachers to provide appropriate scaffolding, formulate meaningful questions, facilitate evidence-based discussion, and manage students' digital exploration. Future research should therefore involve larger and more diverse samples, longer intervention periods, and multiple outcome variables to provide stronger evidence regarding the effectiveness and sustainability of Digital Inquiry-Based Learning based on environmental problems.

Recommendations

Based on the findings and limitations of this study, several recommendations can be proposed. First, elementary school teachers are encouraged to integrate Digital Inquiry-Based Learning with authentic environmental problems that are relevant to students' daily lives. Local issues such as flooding, waste management, water pollution, and reduced green spaces can provide meaningful contexts for developing scientific literacy. Second, teachers should use digital simulations as inquiry tools rather than merely as presentation media. Students should be given opportunities to formulate questions, make predictions, manipulate variables, collect evidence, interpretasi data, and construct scientific explanations based on their findings. Third, schools should provide adequate digital infrastructure, learning resources, and teacher professional development to support the implementation of digital inquiry learning. Teachers need training not only in the technical use of digital platforms but also in designing inquiry activities and providing appropriate scaffolding for elementary students. Fourth, future studies should involve larger and more diverse samples across different schools and geographical contexts to improve the generalizability of the findings. Longitudinal studies are also recommended to examine whether improvements in scientific literacy are sustained over time. Fifth, future research should examine the effects of Digital Inquiry-Based Learning on other learning outcomes, including critical thinking, problem-solving skills, environmental awareness, environmental attitudes, creativity, and environmentally responsible behavior.

Finally, future researchers are encouraged to develop more interactive and context-sensitive digital simulations that allow students to investigate complex environmental phenomena and formulate evidence-based solutions. Integrating digital inquiry with local environmental data, citizen science activities, and real-world environmental projects may further strengthen the connection between scientific literacy and students' everyday lives.

Author Contributions

Sulistyani Puteri Ramadhani. The author was responsible for all aspects of the study, including conceptualization, research design, development of the Digital Inquiry-Based Learning intervention, development and validation of the research instruments, data collection, data analysis, interpretation of findings, manuscript preparation, revision, and final approval of the manuscript.

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