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Integrating Digital Technology into Disaster Education and Its Impact on Elementary School Students' Literacy and Resilience

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Abstract: Integrating Digital Technology into Disaster Education and Its Impact on Elementary School Students' Literacy and Resilience. Indonesia is one of the countries with the highest risks of natural disasters in the world; hence, disaster education in elementary schools is an urgent need. **Objective:** This study aims to analyze the effectiveness of digital technology-based disaster education in improving the disaster literacy and resilience of elementary school students in areas prone to volcanic eruptions. **Methods:** This study used a quasi-experimental design with a nonequivalent control group design. The research sample consisted of elementary school students living in disaster-prone areas. The instruments used included a disaster literacy test, a resilience questionnaire, and interviews with teachers and students to strengthen the quantitative results. Data analysis was conducted using a paired sample t-test to examine differences within groups and an independent sample t-test to compare differences between groups. **Findings:** The results showed a significant increase in the experimental group compared to the control group. The disaster literacy score in the experimental group increased from 47.67 to 82.17, and the resilience score from 58.60 to 80.30. Meanwhile, the control group only experienced a lower increase. The paired sample t-test results showed a significant difference ($p < 0.05$). The control group did not experience a significant increase in the number of participants. The independent sample t-test also confirmed a significant difference between the two groups in their posttest scores, with an average difference of 15.84 points for disaster literacy and 14.30 points for resilience. Qualitative data supported these results, with teachers rating interactive digital media as facilitating the understanding of evacuation and simulations, while students found the learning more engaging and easier to practice. **Conclusion:** This study demonstrates that digital technology-based disaster learning is more effective than conventional methods in enhancing the literacy and resilience of elementary school students. The implication is the importance of integrating digital technology into the disaster education curriculum, so that students not only understand the theory but are also able to adapt, be resilient, and take appropriate action when facing disasters in their environment.

Keywords: disaster education, technology, digital, disaster literacy, disaster resilience.

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INTRODUCTION

Indonesia is recognized as one of the countries with the highest disaster risk in the world (Heo et al., 2023; Faradiba et al., 2025) due to its location within the Ring of Fire (Fahlevi et al., 2019; Sandel et al., 2020). From 1900 to 2025,

EM-DAT reported that disasters in Indonesia affected 44,904,312 people, resulting in 190,031 deaths and 187,700 injuries (Syukri et al., 2025; Parrott et al., 2025). Natural disasters have a significant impact on human well-being, both in the short and long term (Srigyan & Fortun, 2025; Hussain & Mukhopadhyay, 2024; Jarriel et al., 2025). These impacts include mental health (Makwana, 2019), mortality and morbidity (Bourque et al., 2007), economic growth (Cavallo et al., 2013), financial stability and consumption (Bui et al., 2014), and environmental damage that threatens community livelihoods (Demirdag & Nirwansyah, 2024; Ju et al., 2024). Studies show that the frequency of natural disasters has increased dramatically (Zhou & Botzen, 2021; Boudreaux et al., 2023). Geological threats, such as volcanic eruptions, have multidimensional impacts, including in Yogyakarta, which is situated on the slopes of Mount Merapi. Every time an eruption occurs, not only are the local environment and economy affected, but the education sector also suffers damage to infrastructure, disruption to the learning process, and weak preparedness among students to deal with disasters (Atmojo et al., 2023; Atmojo, 2021; Atmojo et al., 2018; Atmojo et al., 2020).

This phenomenon confirms that disaster education is an urgent need from an early age (Méndez et al., 2020; Panwar & Sen, 2019; Rondeau et al., 2020), as it has numerous impacts. Schools can play an important role in disaster preparedness, response, and recovery (Opabola & Galasso, 2024; Mutch, 2018), so that the cultivation of disaster literacy and resilience needs to include not only knowledge, but also attitudes and practical skills so that students can respond appropriately when faced with crisis conditions. However, the reality on the ground indicates that disaster education in elementary schools remains sporadic, unstructured, and often only provided when a disaster occurs or through ceremonial activities. Disaster-related material has not been fully integrated into the curriculum, so students' understanding remains limited to theoretical knowledge without being supplemented by contextual learning experiences. For instance, while students can recite evacuation procedures, they may lack the skills to perform self-rescue simulations in the event of a disaster. Furthermore, the rapid development of digital technology has not been fully leveraged in disaster education. In fact, digital technology has great potential to provide a more realistic, interactive, and contextual learning experience for students (Huang & Chiu, 2021; Al-Amin et al., 2021; Lu et al., 2025; Consoli et al., 2025; Wu, 2024).

A significant opportunity has arisen through the application of digital technology in disaster education. Innovative media such as augmented reality (AR), virtual reality (VR), volcanic simulations, and digital storytelling have been proven to help students understand complex scientific concepts, increase critical awareness of risks, and build more realistic disaster response skills (Bastos, 2021; Lim & Anggraini, 2021; Lagap & Ghaffarian, 2024; Brown & Lee, 2021; Scippo et al., 2024; Zhao et al., 2023). The integration of digital technology enables the creation of immersive learning experiences, where students are directly involved in emergency simulations, practice making quick decisions, and hone their emotional and psychomotor readiness. Thus, disaster education is not limited to knowledge transfer but also serves as a means of developing disaster literacy, resilience, and 21st-century skills relevant to the needs of students in the digital age.

The gap arises because most previous studies have focused on disaster literacy based on theory or conventional approaches using passive print and audiovisual media (Strojny & Du¿mañska-Misiarczyk, 2023; Mahmud & Priyambodo, 2021). In fact, real needs in the field require contextual, interactive learning that is relevant to local conditions. Additionally, the specific application of digital technology in disaster

education at the elementary school level, particularly in areas prone to eruptions of Mount Merapi, remains relatively limited (Hügel & Davies, 2024). Therefore, this research is both important and urgent in presenting innovations in disaster learning integrated with digital technology. The focus of this research is not only on improving disaster literacy but also on strengthening the resilience of elementary school students in disaster-prone areas. With this approach, students not only understand disasters theoretically but also have the readiness and skills to face real threats. This innovation is expected to shape a young generation that is resilient, adaptive, and ready to face disaster risks from an early age.

METHOD

Participants

This study was conducted in an elementary school located in an area prone to volcanic disasters. The study population consisted of all elementary school students in the area. The study sample consisted of two classes, each with a total of 30 students, divided into an experimental group and a control group. The sampling technique was purposive, taking into account the equality of student characteristics and school conditions, to maintain internal validity and comparability between groups.

Research Design and Procedures

This study used a quasi-experimental design with a nonequivalent control group design (Fraenkel & Wallen, 2008). The independent variable was digital technology-based disaster learning, while the dependent variables included students' disaster literacy and resilience. The research procedure was carried out in three main stages. First, the preparation stage involved the purposive selection of schools and classes based on criteria such as location in volcanic disaster-prone areas, the preparation of learning tools, and the testing of instruments. Second, the implementation stage, which involved administering a pretest to both groups, followed by treatment. The experimental group received disaster education through digital technology, integrating several applications and learning media. Volcanic process simulations were conducted using PhET Interactive Simulations software to provide a visual representation of the mechanisms involved in volcanic eruptions. Additionally, interactive animated videos enriched with digital quizzes, based on the Kahoot! and Quizizz platforms, were used to reinforce students' understanding and provide direct formative evaluation. This learning was also reinforced by the use of Augmented Reality (AR), which displayed three-dimensional models of volcanoes, evacuation routes, and rescue scenarios that could be projected through students' devices, making the learning experience more realistic and contextual. The intervention was administered three times, with a duration of 2 x 35 minutes at each meeting, over a period of two weeks. Meanwhile, the control group followed conventional learning methods commonly used in schools, namely lectures and question-and-answer sessions with the aid of textbooks and blackboards without the support of interactive digital media. Third, the evaluation stage, which consisted of a posttest to measure the difference in learning outcomes after the intervention. The research design can be illustrated in Table 1.

Table 1. Research design

Group	Pretest	Treatment	Posttest
Experiment	O_1	Disaster learning based on digital technology	O_2
Control	O_3	Conventional learning	O_4

Furthermore, like quasi-experiments in general, this design has the advantage of allowing direct comparison between the control and experimental groups, but it also has limitations. One of these is the potential emergence of confounding variables, such as environmental factors, students' backgrounds, or differences in teachers' experiences, that can affect the study's results. To minimize potential bias, researchers not only standardized teaching materials and learning time allocation, but also paid attention to potential confounding variables on the part of teachers. Both groups were guided by teachers with equivalent qualifications and experience, and were given the same learning implementation guidelines. This was done so that any differences in results could be more reliably attributed to the digital technology-based disaster learning treatment, rather than to teacher factors. The learning environment was also carefully controlled to ensure that the learning process occurred in a stable and distraction-free setting. Thus, although the quasi-experimental design has limitations, the implementation of disaster learning based on digital technology integration still presents a significant opportunity to improve disaster literacy and student resilience, as long as external variables can be properly controlled.

Instrument

This research used several types of data collected through various techniques and instruments. Each type of data has an appropriate collection instrument, ensuring that the results obtained are valid and can be analyzed accurately. This research instrument comprises a disaster literacy test and a student resilience questionnaire, as presented in Tables 2 and 3.

Table 2. Disaster literacy indicators

Aspects	Indicator
Knowledge	List the early signs of a volcano erupting (thick smoke, rumbling sounds, ash rain, sulfur smell).
	Explaining the main hazards of volcanic eruptions (hot clouds, lava, ash rain, incandescent rocks).
	Knowing the evacuation routes and safe gathering points around the school/home.
	Mentioning important equipment during an eruption evacuation (mask, head cover, drinking water, flashlight, small radio).
	Know the parties or institutions that provide official information about eruptions (BPBD, PVMBG, BNPB, teachers, village officials).
Attitude	Display an alert attitude when a warning of a volcanic eruption is issued.
	Do not panic, remain calm, and follow the directions of teachers/parents during evacuation.
	Comply with the evacuation route rules and do not return to retrieve items during an emergency.
	Have a caring attitude by helping friends who are having difficulties during evacuation.
	Maintain health by wearing a mask during ashfall.
Skills	Practicing how to protect yourself during ashfall (wearing a mask, covering your head, protecting your eyes).
	Practicing the correct evacuation steps to a safe gathering point.
	Drawing a simple map of evacuation routes from home/school to a safe place.
	Prepare a special disaster preparedness bag for volcanic eruptions (drinking water, snacks, medicines, masks, flashlights, clothes).
	Actively participate in volcano eruption evacuation simulations at school.

Table 3. Disaster resilience indicators

Aspect	Indicator
Emotional	Able to remain calm when hearing danger signs of eruption (sirens, announcements).
	Not panicking excessively when there is ash rain or rumbling from the mountain.
	One can control fear by performing the rescue actions that have been taught.
Cognitive	Understand that volcanic eruptions are natural events that can be faced with preparedness.
	Know the steps for self-protection during ashfall, hot cloud, or evacuation.
	Able to remember and explain evacuation routes and safe gathering points.
Behavior	Follow the directions of teachers or parents regarding discipline during simulations or evacuations.
	Using personal protective equipment (PPE), such as masks and headgear, correctly.
	Do not return to take valuables when being evacuated.
	Actively participate in volcano evacuation simulations at school.
Social	Able to cooperate with friends during evacuation (e.g., waiting for each other, helping weak friends).
	Willing to share emergency equipment with friends who do not carry.
	Respect and follow the directions of teachers, parents, or village officials.
Optimism & Recovery	Remaining eager to return to learning after a simulation or eruption event.
	Have confidence that disasters can be faced together with preparedness.
	Showing gratitude and not giving up easily after going through an emergency experience.

Before the instruments were used in data collection, all research instruments were first validated by three experts in the field of disaster learning development and educational technology. Validation was conducted to ensure that the instrument items accurately measured indicators of disaster literacy and resilience in accordance with the research objectives. In addition to expert validation, empirical validation was also conducted through trials on groups of students with characteristics similar to those of the research sample. The validity test results showed that all instrument items were valid, with correlation coefficients above the minimum required. The reliability test revealed that the instrument had a Cronbach's Alpha value of 0.828, indicating high reliability. This indicates that the instrument is suitable for use in research. With instruments that have been proven valid and reliable, the data obtained from the learning process can be trusted to be analyzed further.

Data Analysis

The collected data were then analyzed through several stages. Prior to hypothesis testing, prerequisite analysis was conducted to ensure that the data met the assumptions of parametric statistics. A normality test was conducted using the Kolmogorov-Smirnov and Shapiro-Wilk methods, while the variance homogeneity test was conducted using Levene's Test. These two tests aim to ensure that the data is normally distributed and the variance between groups is relatively the same, so that the selection of parametric tests can be statistically justified.

Once the data meet the prerequisites for analysis, the next step is to conduct hypothesis testing to evaluate the effectiveness of digital

technology-based disaster learning. Hypothesis testing is conducted through several stages of statistical analysis to provide a comprehensive understanding of the differences in learning outcomes between the experimental and control groups. First, a Paired Sample t-test was conducted to determine whether there was a significant difference between the pretest and posttest scores in the experimental group. This test evaluates the effectiveness of digital technology-based disaster learning in enhancing disaster literacy and student resilience within the experimental group.

Furthermore, an Independent Sample t-test was conducted to compare the post-test scores between the experimental and control groups. This test can determine whether there is a significant difference in improving disaster literacy and resilience between students who participate in digital technology-based disaster learning and those who participate in conventional learning. The results of this test serve as the basis for evaluating the superiority of digital technology-based learning interventions over traditional learning approaches.

All statistical tests were conducted using SPSS software version 25 with a significance level (á) of 0.05. This means that the test results are considered significant if the p-value is less than or equal to 0.05. This analysis provides a strong basis for evaluating the effectiveness of disaster learning with digital technology integration in developing disaster literacy and resilience skills of elementary school students. Thus, the data analysis technique used not only provides an overview of the intervention's effectiveness but also ensures that the research results have strong internal validity can be scientifically accounted for.

RESULT AND DISCUSSION

In disaster-prone areas, education plays a crucial role in equipping students with the knowledge, skills, and attitudes necessary for disaster preparedness and resilience. The integration of digital technology in disaster education not only makes it easier for students to understand natural phenomena through simulations, visualizations, and interactive media but also helps them develop a practical understanding to deal with emergencies more adaptively. Through the use of digital technology, disaster literacy can be enhanced, enabling students to recognize risks, understand mitigation strategies, and cultivate a resilient attitude in the face of potential disasters in their environment.

In line with this perspective, this research was conducted in schools located in areas prone to volcanic eruptions. The aim is to measure the effectiveness of digital technology-based disaster learning in improving the disaster literacy and resilience of elementary school students. The results of the research data description regarding students' disaster literacy and resilience are presented in Table 4.

Table 4. Data description

Variable	Group		Statistic
Disaster literacy	Pretest Experiment	Mean	47.6667
		Variance	6.437
		Std. Deviation	2.53708
	Experiment Posttest	Mean	82.1667
		Variance	6.902
		Std. Deviation	2.62722
	Control Pretest	Mean	46.2667
		Variance	6.754
		Std. Deviation	2.59885

	Control Posttest	Mean	66.3333
		Variance	6.161
		Std. Deviation	2.48212
Disaster Resilience	Experiment Pretest	Mean	58.6000
		Variance	4.179
		Std. Deviation	2.04427
	Experiment Posttest	Mean	80.3000
		Variance	16.631
		Std. Deviation	4.07812
	Control Pretest	Mean	57.8667
		Variance	3.499
		Std. Deviation	1.87052
	Control Posttest	Mean	66.0000
		Variance	32.690
		Std. Deviation	5.71749

Based on Table 4, the experimental group's average (M) pretest result in disaster literacy is 47.67, which is relatively comparable to the control group's average of 46.27. After the intervention, the average post-test score of the experimental group increased significantly to 82.17, while the control group reached only 66.33. A similar trend was observed in the aspect of disaster resilience, where the experimental group's pretest average of 58.60 was nearly identical to that of the control group, at 57.87. However, in the experimental group's posttest, the average score increased to 80.30, higher than that of the control group, which reached only 66.00. The variance and standard deviation in both groups showed a relatively stable distribution of data, allowing for the increase that occurred to be considered consistent. Thus, these descriptive results show that the learning intervention had a greater positive impact on improving disaster literacy and resilience in the experimental group compared to the control group.

To clarify the difference, Figures 1 and 2 present the visualization in the form of a radar chart, which shows the outward shift of the line as a representation of increased student competence.

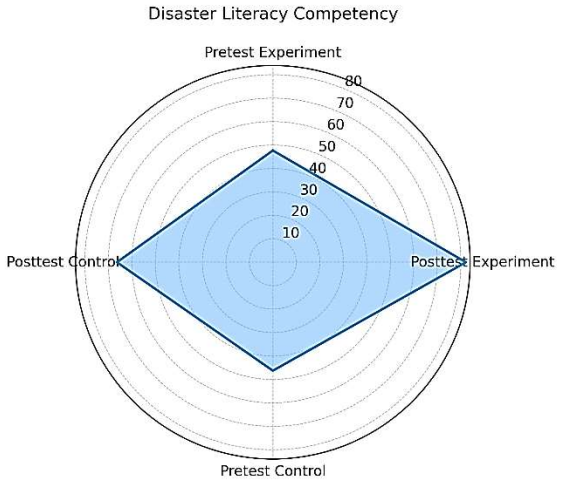

Figure 1. Mean comparison of disaster literacy

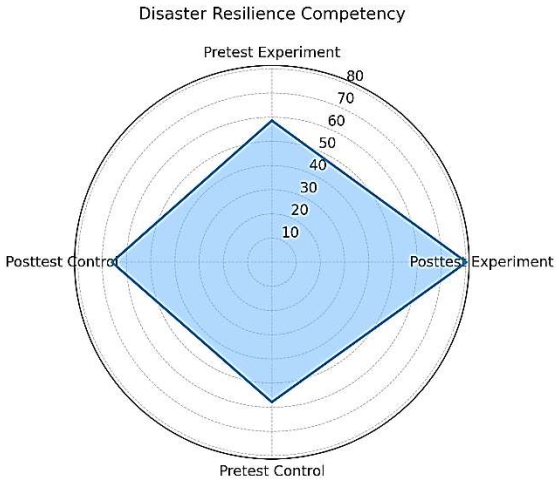

Figure 2. Mean comparison of resilience

Figure 1 provides a visualization of the average disaster literacy competencies based on pretest and posttest results in the experimental and control groups. Lines that move further outward indicate an increase in ability. It can be observed that the experimental group showed a greater improvement than the control group following the learning intervention. Furthermore, Figure 2 displays the average disaster resilience competency in both groups. The pattern is similar to disaster literacy, where the experimental group's post-test line moves further outward than the control, indicating that the intervention has a significant effect in improving students' resilience.

Furthermore, before conducting a hypothesis test to confirm the significance of the difference, the normality assumption test was first carried out on the research data. The results of the normality test are presented in Table 5.

Table 5. Normality test results

Variable	Group	Kolmogorov-Smirnov [a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Disaster literacy	Pretest Experiment	.111	30	.200*	.974	30	.665
	Experiment Posttest	.105	30	.200*	.967	30	.448
	Control Pretest	.120	30	.200*	.970	30	.526
	Control Posttest	.087	30	.200*	.967	30	.469
Resilience	Experiment Pretest	.116	30	.200*	.969	30	.499
	Experiment Posttest	.125	30	.200*	.964	30	.400
	Control Pretest	.138	30	.148	.955	30	.228
	Control Posttest	.102	30	.200*	.961	30	.335

Based on Table 5, the results of the normality tests using the Kolmogorov-Smirnov and Shapiro-Wilk tests indicate that all data, in both aspects of disaster literacy and disaster resilience, have a significance value (Sig.) greater than 0.05. In disaster literacy, the Shapiro-Wilk significance values were 0.665 for the experimental pretest group, 0.448 for the experimental posttest, 0.526 for the control pretest, and 0.469 for the control posttest. Similarly, in disaster resilience, the experimental pretest Shapiro-Wilk significance value was 0.499, the experimental posttest 0.400, the control pretest 0.228, and the control posttest 0.335. These results indicate that all data are normally distributed, as the significance value is greater than 0.05, thus fulfilling one of the basic assumptions for parametric tests in further analysis.

Because the normality test results show that all data are normally distributed, the next step is to conduct a variance homogeneity test. This test aims to ascertain whether the data in the experimental and control groups have the same or homogeneous variance. The homogeneity test results are presented in Table 6.

Table 6. Homogeneity test results

		Levene Statistic	df1	df2	Sig.
Disaster literacy	Based on Mean	.072	1	58	.790
	Based on Median	.067	1	58	.797
	Based on Median and with adjusted df	.067	1	57.848	.797
	Based on the trimmed mean	.058	1	58	.811

Resilience	Based on Mean	.784	1	58	.380
	Based on Median	.124	1	58	.726
	Based on Median and with adjusted df	.124	1	45.518	.727
	Based on the trimmed mean	.423	1	58	.518

Based on Table 6, the results of the homogeneity test using the Levene Test show that the disaster literacy data have a significance value of 0.790. In contrast, the disaster resilience data has a significance value of 0.380. It is indicated that the variance between the experimental and control groups is homogeneous. Thus, the data meet the assumption of homogeneity, allowing parametric tests to be continued.

Since the data meet the assumptions of normality and homogeneity, the analysis can proceed with the paired sample t-test. This test is used to determine the average difference in pretest and posttest results in the same group, both in the experimental and control groups. The paired sample t-test results for disaster literacy are presented in Table 7, while those for disaster resilience are shown in Table 8.

Table 7. Paired sample t-test results for disaster literacy

	Paired Differences		**t**	**df**	**Sig. (2-tailed)**
	95% Confidence Interval of the Difference				
	Lower	**Upper**			
Pretest_Posttest	-34.79007	-34.20993	-243.254	29	.000

Based on Table 7, the paired sample t-test results on disaster literacy reveal a highly significant difference between pretest and posttest scores in the experimental group. The analysis yielded a t value of "243.254 with a degree of freedom (df) of 29 and a significance value (Sig. 2-tailed) of 0.000 (<0.05). The extremely large t-value occurred because the variation in difference scores among participants was very small (SD = 0.78), indicating that almost all students experienced a similar improvement of approximately 34–35 points. This confirms a consistent and significant increase in disaster literacy after the implementation of disaster learning with digital technology integration.

Based on Table 8, the paired sample t-test results on disaster resilience also show a significant difference between pretest and posttest

Table 8. Results of paired sample t-test of disaster resilience

	Paired Differences		**t**	**df**	**Sig. (2-tailed)**
	95% Confidence Interval of the Difference				
	Lower	**Upper**			
Pretest_Posttest	-23.25714	-20.14286	-28.502	29	.000

scores in the experimental group. The *t* value is -28.502 with a degree of freedom (df) of 29 and a significance value of 0.000. This finding suggests that integrating digital technology into disaster learning has a significant impact on increasing students' disaster resilience.

After analyzing the paired sample t-test in the experimental group, significant differences were found between the pretest and posttest results in both disaster literacy and disaster resilience. However, to obtain a more comprehensive picture of the effectiveness of this

intervention, a comparison of the results between the experimental group and the control group is needed. Therefore, an independent sample t-test was conducted to test the significance of the average difference in posttest results on disaster literacy and disaster resilience (Table 9) between the two groups.

The results of the independent sample t-test, presented in Table 9, indicate a significant difference between the experimental group and

Table 9. Independent t-test results

		t-test for Equality of Means				
		t	**df**	**Sig. (2-tailed)**	**Mean Difference**	**Std. Error Difference**
Disaster Literacy	Equal variances assumed	23.994	58	.000	15.83333	.65988
	Equal variances not assumed	23.994	57.814	.000	15.83333	.65988
Disaster resilience	Equal variances assumed	11.153	58	.000	14.30000	1.28219
	Equal variances not assumed	11.153	52.441	.000	14.30000	1.28219

the control group in terms of disaster literacy and resilience. For disaster literacy, a p-value of 0.000 indicates that a digital-based disaster education intervention has a significant effect on improving students' disaster literacy. Furthermore, the effect size calculation using Cohen's d shows a value of 6.20, which is classified as a very large effect. This indicates that the intervention not only had a statistically significant impact but also had a very strong practical influence on improving students' disaster literacy.

Meanwhile, the resilience variable showed a p-value of 0.000, indicating that the intervention also significantly improved student resilience. Effect size analysis using Cohen's d yielded a value of 2.88, which falls within the very large effect category. These results demonstrate that the intervention is highly effective in strengthening students' resilience in the face of disasters. Thus, the digital-based disaster education program has been proven effective in improving disaster literacy while also having a significant influence on strengthening student resilience.

In addition to the statistical test results, field findings through interviews also strengthen the effectiveness of the program. Teachers reported that the digital approach in disaster education provides a more contextual and meaningful learning experience for students.

Teacher 1 revealed: *"Previously, students only knew about volcanic eruptions from books. However, with digital animations and simulations, they can better visualize how the process works. Even when I asked them again, they could not explain in their own language."* Teacher 2 added: *"Interestingly, students not only understand the content better, but also seem more prepared when I ask them to discuss evacuation steps. They are becoming accustomed to planning for potential disasters. I think that is a form of resilience that is starting to form."*

From the students' side, the responses also showed high enthusiasm. Student A stated: *Learning about volcanoes using videos is fun, so I know why they erupt. If I just read a long text, it is difficult, but if I see the animation, I immediately understand."* Student B said: *"I know that if there is a siren, I have to get out*

quickly and not panic. I used to be very afraid of hearing stories of volcanic eruptions, but now I am braver because I already know what to do." Student C added: *"When there was an evacuation simulation, I felt like there was really a disaster. So now I have memorized the safe exit routes."*

The results of these interviews show that the integration of digital technology not only improves students' academic understanding but also shapes their real preparedness and confidence in facing disasters. Thus, the qualitative data reinforce the quantitative results that digital-based disaster learning not only improves students' literacy and knowledge but also shapes the attitudinal readiness, skills, and resilience essential in dealing with disaster risks.

These findings align with previous studies that emphasize the importance of experiential learning in enhancing disaster preparedness. For example, research by Liu et al (2024) found that student involvement in simulations and contextual activities significantly increased disaster awareness and mitigation skills. Similarly, studies by Noviana et al (2023) and Atmojo et al. (2023) emphasize that science-based disaster education can strengthen community resilience from an early age. This emphasis on contextual and participatory aspects aligns with the constructivist view that knowledge is more meaningful when linked to real-life experiences (Lin et al., 2025; Anjini et al., 2022). In line with this, Sahudra et al. (2025) and Mudassir (2025) also emphasize that experience-based disaster learning not only strengthens cognitive understanding but also builds emotional readiness and practical skills in dealing with crises. Thus, the results of this study reinforce the importance of an experience-based and contextual approach to disaster education, which aims to instill literacy and build resilience from the primary education level onwards.

However, this study also presents new findings that enrich the literature on disaster education. The results show that disaster education not only influences the improvement of cognitive knowledge or disaster literacy but also has a significant impact on psychosocial aspects, as evidenced by student resilience. Resilience in this context is not only understood as the ability to recover after a disaster, but also includes courage, mental preparedness, emotional control, and the ability of students to remain calm and rational in the face of potential threats (Bekircan et al., 2025; Mao et al., 2025). Thus, disaster education serves a dual purpose: on the one hand, it increases students' understanding of risks and mitigation measures, and on the other hand, it strengthens the affective aspects that shape a culture of preparedness from an early age. These findings align with Nasution's view, which emphasizes that community resilience is not only built through knowledge capital, but also through psychosocial capacity that enables individuals to cope with stressors more adaptively. In the context of basic education, building student resilience is very important because children are among the groups most vulnerable to the impacts of disasters (Winarti & Barbara, 2023).

The practical implications of this study emphasize the importance of integrating disaster science education into school curricula, especially in areas prone to volcanic disasters. This integration needs to be carried out systematically and continuously so that disaster education is not only incidental but also capable of fostering a culture of disaster awareness among students. This culture will shape the correct mindset and behavior in responding to disasters, making it part of daily habits (Shiwaku & Fernandez, 2011; Khaerudin & Suharto, 2022). In practice, teachers can employ various contextual approaches, including evacuation simulations, simple risk assessments in the school environment, science experiments on volcanic phenomena, and discussions based on local case studies. This integration not only improves disaster literacy but also builds resilience in students, which in turn will help reduce the risk of casualties in the future.

However, this study has several limitations. First, the study was conducted in only one region with a limited sample, so the results should be interpreted with caution. Second, the duration of the intervention was relatively short (only a few meetings), so the long-term impact of disaster science education on students' actual behavior is not yet fully apparent. Third, the instruments used to measure resilience were mostly questionnaires, so the possibility of perception bias remains open.

Based on these limitations, further research can be directed at three main recommendations. First, expand the research locations to other disaster-prone areas (such as floods, earthquakes, and tsunamis) to assess the effectiveness of the same approach in different contexts. Second, conduct a longitudinal study to measure the long-term impact of disaster learning on students' real behavior in dealing with emergencies. Third, develop a more comprehensive resilience measurement instrument by incorporating observational data on real behavior in disaster simulations.

Thus, the results of this study make an important contribution to the disaster education literature. Theoretically, this research strengthens the science-based contextual learning model as a practical approach to improving students' literacy and resilience. Practically, this research provides a basis for schools and policymakers to integrate disaster education into the basic curriculum as a strategic effort to build a generation that is better prepared to face disaster risks in the future.

■ CONCLUSION

Based on the research results, it can be concluded that disaster learning integrated with digital technology is effective in improving the disaster literacy and resilience of elementary school students in areas prone to volcanic eruptions. This is evident from the increase in pretest to posttest scores in the experimental group, which is significantly higher than those in the control group. In the experimental group, the disaster literacy score increased from 67.45 to 84.12, and the resilience score increased from 65.87 to 82.76, with paired sample t-test results showing significance at the level of 0.05. Meanwhile, the results of the independent sample t-test also confirmed a significant difference between the experimental group and the control group on the posttest score. The effect size analysis, using Cohen's d, showed values of 6.20 for disaster literacy and 2.88 for resilience, both of which fall into the very large effect category. These quantitative findings are reinforced by the interview results, which show that teachers emphasize that integrating disaster learning with interactive digital media makes it easier for students to understand evacuation materials, disaster simulations, and safety steps in a more contextualized manner. Students also stated that learning was more interesting and easier to understand through digital simulations, as they not only trained cognitive understanding of concepts but also fostered affective readiness and responsibility in facing disasters. Thus, technology-based disaster education not only improves students' conceptual understanding but also strengthens their confidence, preparedness, and procedural understanding in facing disasters. However, it does not yet comprehensively cover long-term emotional recovery skills. These findings suggest that disaster education in elementary schools should integrate digital simulations with hands-on activities, such as routine drills and basic psychosocial guidance, to foster students' resilience in a more comprehensive manner.

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