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# INNOVATIVE INTEGRATED DISASTER EDUCATION IN PHYSICS LEARNING: AN EFFORT TO ENHANCE STUDENTS' DISASTER LITERACY SKILLS

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**ABSTRACT**

Disaster-prone regions require an education system that equips students with both scientific understanding and disaster preparedness. However, integration of disaster mitigation content into subject-specific learning, particularly physics, remains limited. This study aims to develop and evaluate the effectiveness of physics teaching materials integrated with disaster mitigation education to enhance students' disaster literacy skills. A mixed-method approach with an exploratory sequential design was employed. The development process followed the 4D model (Define, Design, Develop, and Disseminate) to design and implement teaching materials systematically. The study was conducted in two high schools in South Lampung Regency, Lampung, Indonesia, involving four classes (two experimental and two control groups) with a total of 128 students, comprising 63 students in the experimental group and 65 in the control group. The T-test results show that the use of disaster mitigation-based teaching materials had a statistically significant effect on students' disaster literacy abilities, with a significance value of 0.000 ($p < 0.05$). The results of the effect size analysis (Cohen's $d = 0.62$ and 0.66) fall within the moderate category, confirming that this intervention had a significant impact on enhancing students' disaster literacy skills related to disaster mitigation. The implementation of this teaching material not only enhances students' understanding of physics concepts but also increases their awareness and preparedness for disasters, particularly in terms of disaster literacy, making it a strategic innovation in disaster education. This research makes a significant contribution to the development of disaster education curricula in Indonesia, particularly within the context of physics education.



Keywords: disaster literacy; disaster mitigation; natural disaster education; physics learning

## INTRODUCTION

Natural disasters, such as floods, volcanic eruptions, tsunamis, and earthquakes, are unavoidable events that can cause property damage and loss of life (Massazza et al., 2019; Darmawan et al., 2020). Despite numerous efforts, the limits in predicting or completely preventing disasters pose significant risks to people's lives and the environment (Hidalgo & Baez, 2019; Urlainis et al., 2022). Earthquakes are among the numerous natural disasters that affect the majority of people. Large earthquakes occurred in Haiti (Ten et al., 2020), Chile (Melgar et al., 2017), and Japan (Rehdanz et al., 2015). Even in Indonesia, Aceh saw the biggest earthquake and tsunami, killing around 227,898 people (Pre et al., 2012; Widiatmoko et al., 2019Rusydy et al., 2020). These occurrences highlight the general public's lack of readiness for possible disasters.

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The community's lack of preparedness in the face of probable disasters stems from a lack of disaster mitigation education. Previous research has attempted to enhance disaster mitigation by developing models (Juhadi et al., 2021), investigating effective strategies for disaster mitigation integration (Septikasari et al., 2024a), designing school disaster education programs (Gokmenoglu et al., 2021), raising knowledge about disasters and their effects (Kimura & Aikawa, 2024), and using disaster-specific learning approaches (Tyas et al., 2020). However, understanding of disaster mitigation remains inadequate (Deta et al., 2019; Astuti et al., 2021; Rahmawati et al., 2024), necessitating more efforts to expand knowledge of disaster mitigation. Disaster preparedness education should begin at a young age, as it can help individuals develop their knowledge, skills, and understanding (Abdillah et al., 2020). Disaster management education has also been beneficial in raising understanding and enhancing disaster response skills (Schilly et al., 2024). Previous research has highlighted a variety of disaster mitigation strategies that can increase preparedness, including government support, personal protection, and health education (Wang et al., 2022).

Learning serves as a fundamental means of educating individuals about disaster mitigation. Physics education plays a crucial role in fostering a deeper understanding of natural phenomena, including common disasters. Through the study of physics, students can comprehend the fundamental principles underlying events such as earthquakes and tsunamis. This aligns with findings from preliminary studies, which indicate that school disaster education requires urgent attention to contribute effectively to disaster preparedness (Saregar et al., 2022). Understanding these principles enables students to be better prepared and to respond more effectively to natural disasters. Effective disaster mitigation instruction necessitates the use of appropriate teaching materials. Instructional materials that incorporate technology can offer a more dynamic and interactive learning experience (Netriwati et al., 2023; Bujang et al., 2025). Teaching materials enable learners to access visually rich and interactive educational content from anywhere and at any time, embedding understanding through simulations, videos, and interactive quizzes (Aulia & Yuliani, 2022). This makes the learning process not only relevant but also integrated with daily life practices and disaster preparedness (Munzil et al., 2022; Ismaniati & Iskhamdhanah, 2023; Pratiwi et al., 2023). This transformation not only enhances learning engagement and effectiveness but also ensures that knowledge can be applied in real-world situations, which aligns with 21st-century needs that prioritize technology in problem-solving (Suherman et al., 2021Anggara et al., 2022; Kashyap et al., 2023; Mustafa, 2024).

Previous research has resulted in a variety of disaster mitigation-related learning products, including mobile encyclopedias (Wahyuningtyas et al., 2021), the DIMADU application (Ilyasa et al., 2024), digital comics (Pujaanti & Isnah, 2023), and interactive multimedia (Mardani et al., 2021). In addition, teaching materials for disaster mitigation have been developed for various disasters, including fire (Agustia & Fauzi, 2020), lightning (Fadieny & Fauzi, 2021), and drought (Fourilla & Fauzi, 2021). Some have created teaching material for earthquake disaster mitigation (Purnama et al., 2021; Wahyono et al., 2022). Although innovation in disaster education continues to grow, research that specifically integrates disaster education into formal learning processes is still relatively limited. For instance, Mutasa and Coetzee (2019a) explored disaster education to promote the integration of disaster risk reduction into the primary school curriculum in Botswana. Amri et al. (2022) integrated disaster education to evaluate disaster-safe education units in Indonesia, Azmi et al. (2020) integrated disaster education through learning media as a form of flood disaster mitigation, and Kimura et al. (2017) integrated disaster education to enhance disaster management literacy. However, there is a lack of research specifically focused on the development of teaching materials that integrate disaster education within physics instruction to enhance students' disaster literacy skills, particularly in the context of earthquake and tsunami mitigation. To address this gap, the study aims to develop and implement innovative physics teaching materials that incorporate disaster-related content and mitigation strategies, with the intention of enhancing students' disaster literacy skills. Thus, this study contributes to strengthening the role of physics education through instructional materials in formal learning as a strategic means to enhance disaster literacy and preparedness among students.

## METHODS

A mixed-method approach with an exploratory sequential design was used in this study. The development design uses the 4D model (Define, Design, Develop, and Diseminate) (Fransisca et al., 2019). This model was selected to systematically support the development of innovative disaster education integrated with physics learning. The study was conducted in two schools located in the Kalianda area, Lampung, which was chosen due to its relatively high risk of natural disasters, particularly earthquakes and tsunamis, making it a relevant setting for research focused on disaster literacy in physics education. Utilizing Flip PDF Professional, digital learning materials were developed in accordance with disaster mitigation principles to enhance students' disaster literacy skills. This approach aligns with Distrik et al. (2024), who found that 3D Pageflip PDF can help students enhance their digital literacy skills.

In the define stage, a needs analysis was conducted and relevant literature was reviewed to support the rationale for developing the product. The product design stage comprises several key steps, with the primary focus on designing and developing a digital teaching material format that integrates disaster mitigation content. Additionally, disaster-related animations are created to support and enhance students' understanding of the concepts.

The development stage involves conducting product validation through assessments by four validators – two subject matter experts and two media experts – who evaluate the feasibility of the developed product. Data collection at this stage employs questionnaires designed to assess both the feasibility and the appeal of the teaching materials. Validators utilize a feasibility questionnaire during the validation process, while an attractiveness questionnaire is administered to assess student responses. The data analysis technique employed is quantitative descriptive analysis.

The dissemination stage involves distributing products to test the effectiveness of physics teaching materials integrated with disaster education in enhancing students' disaster literacy. At this stage, validated products are distributed and implemented in schools to evaluate their impact on the learning environment directly.

In the limited field test stage, the study population consisted of 726 grade XI students from SMA Negeri 1 Kalianda and SMA Negeri 2 Kalianda, South Lampung Regency, Lampung, Indonesia. The sampling technique used was purposive sampling, in which 128 students were selected as the sample, consisting of four classes (two experimental and two control groups). The experimental groups consisted of 63 students, while the control groups consisted of 65 students.

The research instrument consists of a non-test questionnaire to measure disaster literacy skills. The instrument was adapted from the guidelines and indicators developed by the National Disaster Management Agency (Badan Penanggulangan Bencana). Disaster literacy indicators encompass knowledge, emergency preparedness, and response plans (PRP), early warning systems (EWS), and resource mobilization (RMC) (Hidayati et al., 2006). The data analysis technique used a t-test to assess the effect of using teaching materials. However, before conducting the test, a prerequisite test is carried out to see the normality and homogeneity.

Meanwhile, the effectiveness of this teaching material is measured using the effect size test. Effect size can be calculated using the formulation from Cohen (1998). Effect size (d) calculated by taking the difference between the average gain value in the experimental group and the average gain value in the control group. This difference is then divided by the combined standard deviation of the two groups. The combined standard deviation is calculated by taking the average of the squares of the standard deviations of the groups, then taking the square root.

Generally, the effect size indicates the magnitude of the difference produced by the treatment or intervention in the study. The greater the effect size value, the stronger the impact of the treatment given to the experimental group compared to the control group. The criteria for the size of the effect size can be seen in Table 1.

**Table 1**. Effect Size Criterion

| Effect Size | Category |
|---|---|
| $d < 0,2$ | Small |
| $0,2 < d < 0,8$ | Medium |
| $d > 0,8$ | High |

## RESULTS AND DISCUSSION

The first stage in developing disaster mitigation-based teaching materials is the Define stage in the 4D development model, including problem identification, need analysis, and determination of learning objectives. Problem identification is conducted to gather information about secondary school learning in Lampung. This process includes literature studies and field observations. The literature review aims to collect information about various teaching materials as a reference in designing more relevant products. Based on the results of the literature study, no physics teaching materials have been developed for disaster mitigation. At the same time, the field observations reveal that teachers frequently utilize the same teaching materials and often rely solely on textbooks. This condition causes students to become easily bored due to the lack of variation in teaching materials. In addition, the learning process does not involve active participation from students, because teachers often deliver material only from textbooks. The results of observations also show that students have a limited understanding of disaster mitigation, including how to respond to disasters when they occur. This emphasizes the importance of creating creative and innovative teaching materials to promote learning and enhance students' disaster literacy. This aligns with Wiwik et al. (2021) and Mutasa and Coetzee (2019b), who emphasize that disaster-based learning is still rarely applied in the formal curriculum.

Based on the results of the problem identification, it was found that more interesting and relevant teaching materials related to disaster mitigation in learning are needed. To address these needs, disaster mitigation-based teaching materials tailored to the characteristics and needs of current students are the ideal solution. These teaching materials are presented in an attractive display, packaged in easy-to-understand language, making it easier for students to grasp the material. Additionally, these teaching materials are also equipped with interactive images and videos, designed to support students' independent learning, allowing them to learn more effectively and enjoyably.

Based on the results of problem identification and needs analysis, a disaster mitigation teaching material was designed for high school students. Through this teaching material, students are expected to understand physics subjects with a focus on natural phenomena related to disaster mitigation mechanics, and to develop learning independence and achieve learning outcomes in the cognitive domain.

At the product design stage, this is achieved by considering various aspects that are crucial for producing effective and engaging teaching materials. The design process begins by determining the appropriate appearance of teaching materials, choosing relevant themes, and incorporating the concept of disaster animations. Comprehensive learning evaluations are also important components in this stage to ensure. The teaching materials can meet students' needs as much as possible.

The initial design of disaster mitigation-based teaching materials centers on selecting and determining the content to be included, taking into account several factors, such as material feasibility, content suitability, readability of language and images, and graphic presentation that aids understanding. This study also considers visually appealing elements to maintain learners' interest. In this case, supporting media, such as videos and images, are intended to complement and enhance the delivery of material in teaching materials, so that learners receive information and actively participate in the learning process. The product was developed in digital format using Flip PDF Professional to enhance interactivity and visual engagement in the learning process.

After determining the content and design of the media, the researchers created test and evaluation instruments. These instruments consisted of validation sheets from media experts, validation sheets from material experts, and questionnaires to assess student responses. These instruments are crucial in ensuring that the teaching materials created meet the expected quality standards and are effective when used in real-world learning environments. The teaching materials are designed with a systematic summary to help students organize and consolidate their knowledge related to the disaster phenomenon and the underlying physics principles. This increases student engagement and understanding (Eukaristia et al., 2023). The teaching materials developed in this study include exercises that enable students to assess their knowledge and ensure they have mastered the material before progressing to the next stage (Tosuncuoğlu, 2018; Kausar, 2022).

The development stage includes product validation by material experts and media experts to assess the feasibility of the developed teaching materials. This validation aims to ensure that the developed teaching materials not only meet the quality standards of content and presentation but are also relevant and effective in facilitating learning. Four experts are divided into two teams: two material experts and two media experts. They carry out the validation process thoroughly. Material experts assess the accuracy, completeness, and organization of content related to learning objectives, while media experts focus on the visuals, interactivity, and readability of the module. Suggestions and input from validators are used as a guide to enhance and refine the design of teaching materials to suit user needs, and can be effectively incorporated into the learning process. This process ensures that the resulting product is truly ready for use in the field, and its quality is guaranteed.

Based on the assessment results from the media expert validator, the disaster mitigation-based teaching materials are deemed suitable for use, following several revisions. Revisions are necessary to improve the quality of teaching materials before they are used in learning. The revisions needed for teaching materials are summarized in Table 2.

**Table 2.** Teaching Material Revision by the Media Experts

| No | Suggestion | Revision |
|---|---|---|
| 1 | The logo of Universitas Islam Negeri Raden Intan Lampung should be placed at the top, and the year on the cover should be removed. | Moving the Universitas Islam Negeri Raden Intan Lampung logo to the top and removing the year from the cover. |
| 2 | The video contained in the teaching material should be replaced with the researcher's voice. | Replacing the video sound in the teaching material with the researcher's voice |
| 3 | The presentation of the teaching material is too colorful, making it difficult for the reader to focus on the content. | Reducing the colors of the teaching material content allows readers to focus on the material more easily. |
| 4 | The teaching material page transition time is too long | Enhancing the operation of the teaching material so that the page transition time is not too long |

The researcher used the revision suggestions from the media expert validator to fix the existing deficiencies. This step aims to enhance and make the teaching materials more suitable for use as physics teaching materials with a broad application. Figure 1 shows the assessment of the media expert validator after the revision process.

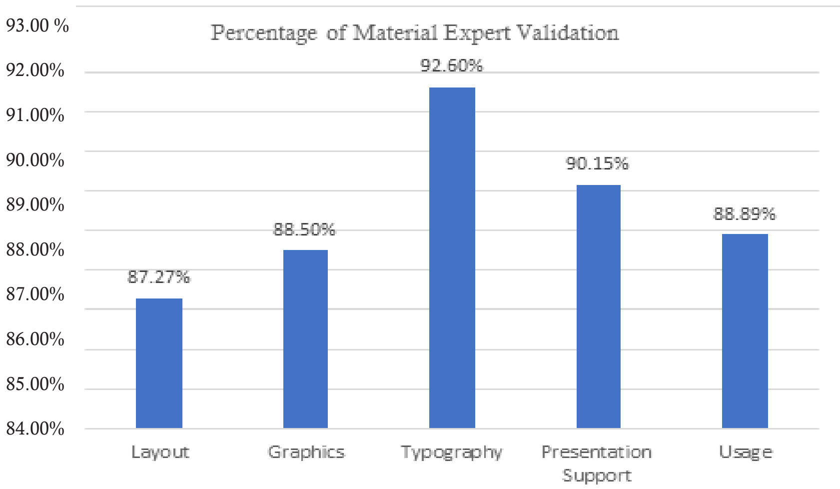


**Figure 1.** The Percentage of Media Expert Validation

Based on the data in Figure 1, the average overall assessment aspect by the two expert media validators was 89.48%, indicating an excellent category. This teaching material employs a consistent selection of fonts, font sizes, and layouts to maintain an orderly appearance while enhancing readability and user comfort (Pratiwi et al., 2021; Hanifah & Ninggolan, 2023). Graphic indicators have also been validated, achieving a score of 88.50%, which falls within a very good category. The blue color theme was chosen because it aligns with the topic of tsunami disaster mitigation related to ocean waves and is expected to instill a sense of calm, confidence, and professionalism in the context of disaster mitigation (Qiu et al., 2019; Wang et al., 2021). The graphical alignment in this teaching material not only increases visual appeal but also effectively strengthens educational content (Widya et al., 2023). While typography in this teaching material is designed with user comfort in mind, as evidenced by the line spacing and the use of text emphasis through bold and italics. Font size, spacing, and text emphasis have a significant impact on how users view and understand information (Ross et al., 2017). Additionally, the appropriate typography in e-learning materials can make the content more engaging and interactive, thereby enhancing the overall learning experience (Beili et al., 2023). This teaching material is equipped with attractive illustrations for the wave and disaster mitigation sections, as well as adequate usage indicators, making it a comprehensive and effective learning tool.

Based on the evaluation results from the Expert validator of the material, the disaster mitigation-based teaching materials are considered feasible to use with several revisions. This revision is necessary to improve the quality of the content, enabling the teaching materials to be used effectively in learning. The revision of the teaching materials is presented in Table 3.

**Table 3.** Teaching Material Revision by the Material Experts

| No | Suggestion | Revision |
|---|---|---|
| 1 | The facts presented are not all reality. | Enhancing the presentation of the material so that the facts presented accurately reflect reality, making it easier to understand. |
| 2 | The images and videos presented are not all actual. | Enhancing some of the images and videos presented so that they are up-to-date |
| 3 | The material presented has not met the standard of language that is easy to understand and does not cause many interpretations. | Enhancing the presentation of the material so that the language used is easy to understand and does not cause many interpretations |
| 4 | Lack of material that contains tsunami disaster preparedness. | Adding material that covers preparedness for tsunami disasters, from before a disaster occurs to after a disaster has occurred. |
| 5 | Symbols, formulas, and foreign terms should be written in italics. | Enhancing the writing of symbols, formulas, and foreign terms by using italic letters. |

Researchers use suggestions for enhancement from expert material validators as a guide to improve weaknesses in teaching materials, especially in the material section. This enhancement was made to ensure that the resulting teaching materials are more suitable for use as physics teaching materials in the learning process. Figure 2 shows the assessment of the material expert validator after the revision process.

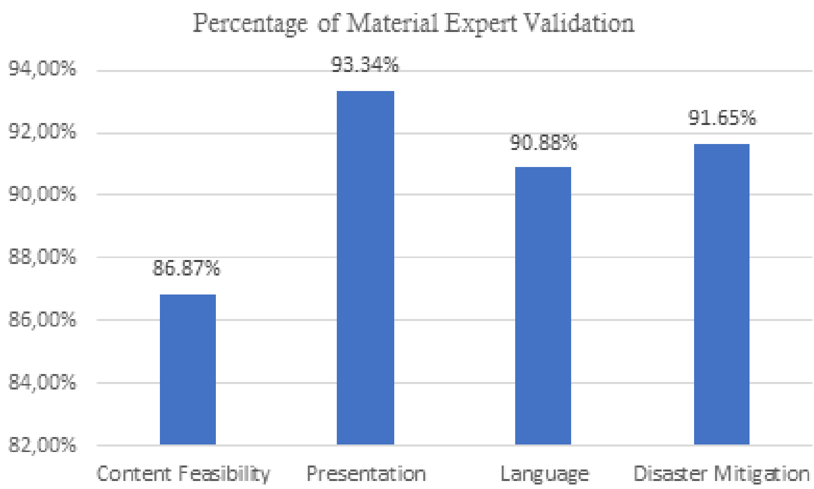


**Figure 2.** The Percentage of Material Expert Validation

Based on the data in Figure 2, the assessment of the validation by material experts on the aspects of content feasibility, presentation, language, and disaster mitigation produced percentages of 86.87%, 93.34%, 90.88%, and 91.65%, respectively. The initial average validation of material experts produced a percentage of 90.69% with very feasible criteria.

It can be seen from the indicators of content, presentation, language, and disaster mitigation feasibility. This teaching material aligns with the learning objectives that have been established. Each topic directly contributes to the development of competencies. This finding is supported by previous research, which indicates that teaching materials should be organized according to learning objectives and competencies (Lestari & Apsari, 2022; Royani & Atun, 2023; Wijayanto et al., 2023). The presentation of the teaching materials is very good, especially in the introduction, which effectively serves as a preview for students. The inclusion of apperception and motivation in each sub-chapter can attract students' interest and encourage them to dig deeper into the material (Handayani et al., 2023). The disaster mitigation indicator received a very good validation score because it explains earthquake and tsunami disaster mitigation using the basic concept of waves in physics. Students not only learn about how waves affect natural events such as earthquakes and tsunamis, but also, for example, the concept of seismic waves is directly related to how earthquakes cause tsunamis. Integrating scientific knowledge with disaster awareness will increase the context and meaning of learning. (Mamadaminova & Khadjikhanova, 2021)

The developed products began to be distributed for use by students in learning activities. At this stage, the developed teaching materials were applied directly in the real classroom following the ongoing learning. Eleventh-grade students who responded to the teaching materials came from two public senior high schools in the South Lampung district. Data were collected using questionnaires distributed to students, which allowed them to assess and respond to the teaching materials. Table 4 shows the students' responses.

**Table 4.** Field Test Learners' Response to Teaching Material in Two Schools

| No | Aspects | $\bar{X}$ | Percentage | Category |
|---|---|---|---|---|
| 1 | Material | 4.75 | 95.00% | Excellent |
| 2 | Language | 4.62 | 92.40% | Excellent |
| 3 | Attractiveness | 4.73 | 94.60% | Excellent |
| | Average | 4.70 | 94.00% | Excellent |

Based on the results of the field test, the presentation aspect of the material received a score of 95.00%, the language aspect received a score of 92.40%, and the interestingness aspect received a score of 94.60%. Based on these three aspects, the average percentage of student responses in both schools was 94%, with the criterion of "very interesting."

Student responses to the field test also helped determine the level of practicality, earning a score of 94.00%, which was categorized as very interesting. The teaching materials contain relevant and structured content, making it easier for students to understand the concepts being taught. The language is also simple and communicative, making it easier for students from various backgrounds to access and understand the material (Syahputra et al., 2023). At the dissemination stage, the teaching material product was implemented in learning for three meetings. Table 5 shows the results of the pre-test and post-test of disaster literacy skills in the experimental and control classes.

**Table 5.** The Results of the Pre-Test and Post-Test Disaster Literacy Skill Scores for the Experimental and Control Classes

| | No | Class | School | Minimum Score | Maximum Score | Average Score |
|---|---|---|---|---|---|---|
| PRE-TEST | 1 | EX 1 | School A | 40.00 | 60.00 | 46.95 |
| | 2 | CON 1 | School A | 38.05 | 55.82 | 44.00 |
| | 3 | EX 2 | School B | 38.00 | 60.00 | 45.00 |
| | 4 | CON 2 | School B | 20.00 | 51.41 | 42.00 |
| POST-TEST | 1 | EX 1 | School A | 78.00 | 95.00 | 85.00 |
| | 2 | CON 1 | School A | 71.00 | 90.00 | 80.00 |
| | 3 | EX 2 | School B | 78.00 | 96.00 | 86.00 |
| | 4 | CON 2 | School B | 70.00 | 90.00 | 80.00 |

This study shows that the use of disaster mitigation-based physics teaching materials has a significant impact on enhancing students' disaster literacy skills. Students' disaster literacy skills are relatively low in both the experimental and control groups before learning. The experimental group and the control group experienced an increase in disaster literacy; however, the increase in the experimental group was significantly different after learning with innovative physics teaching materials integrated with disaster education. The results of the normality test are presented in Table 6.

**Table 6.** Normality Test Results

| | Sample Group (1) | Sig (2) | Conclusion (3) |
|---|---|---|---|
| Disaster Literacy | Experiment 1 | 0,18 | Normal |
| | Control 1 | 0,09 | Normal |
| | Experiment 2 | 0,85 | Normal |
| | Control 2 | 0,56 | Normal |

Based on the results of the normality test presented in Table 6, it can be concluded that the disaster literacy skills data from all sample groups, both the experimental group and the control group, are normally distributed with a Significance value (Sig.) of more than 0,05. This indicates that the normality assumption is met, allowing the data to be further analyzed using parametric tests; furthermore, the results of this homogeneity test are presented in Table 7.

**Table 7.** Homogeneity Test Results

| | F | df1 | df2 | Sig. |
|---|---|---|---|---|
| Disaster Literacy Skills | 1.711 | 3 | 136 | .168 |

Table 7 shows that the variance between the experimental group and the control group is homogeneous, with a significance value of 0.168 (> 0.05). Thus, the data from both groups have comparable variances, allowing further statistical tests to be carried out to examine the differences between the groups. To test the hypothesis regarding the effectiveness of integrated physics teaching materials for disaster education, a t-test was conducted as shown in Table 8.

**Table 8.** T-Test Result

| Dependent Variable | F | Sig. |
|---|---|---|
| Disaster Literacy | 16.255 | .000 |

The results of the analysis reveal a significant difference between the experimental group and the control group in terms of increasing disaster literacy, with an F-value of 16,255 and a Significance Level of P < 0.001. = 0,000 (p < 0,05). This indicates that the use of innovative physics teaching materials based on disaster education has a significant impact on increasing students' disaster literacy skills compared to conventional learning methods. Based on the results of the t-test shown in Table 8, it was found that there was a significant difference in increasing disaster literacy skills between the experimental group and the control group. However, statistical significance alone is not enough to determine the effectiveness of a treatment in practice. Therefore, an effect size analysis was conducted to measure the extent to which the developed physics teaching materials had an impact on increasing students' disaster literacy skills. Table 9 presents the results of the effect size test.

**Table 9.** Effect Size Test Result

| | Class | School | Average Gain (M) | Standard deviation (sd) | Effect Size (d) | Expl. |
|---|---|---|---|---|---|---|
| Disaster Literacy Skills | Experiment 1 | School A | 84, 86 | 8,60 | 0,62 | Medium |
| | Control 1 | School A | 79,51 | | | |
| | Experiment 2 | School B | 86,18 | 8,75 | 0,66 | Medium |
| | Control 2 | School B | 80,35 | | | |

Based on the results of the effect size test shown in Table 9, it was found that the effect size values were in the moderate category, with d = 0.62 for school A and d = 0.66 for school B, which is categorized as a moderate effect (0.2 < d < 0.8). This value indicates that the intervention carried out had a substantive impact on enhancing students' understanding of disaster mitigation. These results confirm that physics teaching materials integrated with disaster education are effective in enhancing students' disaster literacy. These integrated disaster education teaching materials help students connect physics theories with relevant natural phenomena, such as seismic waves in earthquakes and energy propagation in tsunamis, thereby enhancing their disaster literacy. This is in line with Fauza et al. (2021), who analyzed physics teaching materials focused on natural disasters and mitigation, which showed the effectiveness of this integrated approach in secondary education. This is an integrated approach in secondary education. These integrated teaching materials, which incorporate disaster education, connect the learning process to physics through disaster situations. Similar to Kimura et al. (2017), who demonstrate that disaster-based learning can enhance students' awareness and understanding of disaster mitigation strategies through an experiential approach.

Based on the results of the t-test, a significant difference was found between the experimental and control groups, with a significance value of 0.000 ($p < 0.05$). This finding indicates that the use of physics teaching materials integrated with disaster mitigation had a significant impact on improving students' disaster literacy. This difference is closely related to the higher level of student engagement observed in the experimental group compared to the control group. Throughout the learning process, students in the experimental group actively participated in various activities, including group discussions and field investigations. This active involvement enabled them to internalize physics concepts more effectively and relate them to real-world contexts, particularly disaster mitigation. Such a high level of participation contributed to deeper conceptual understanding, which was ultimately reflected in the students' improved outcomes. Learning in this process emphasizes the direct exploration of disasters related to physics, enabling students to construct a more profound understanding, which in turn increases their disaster literacy. Besides that, students not only read theory but also analyze data, conduct simulations, and interpret the physical impacts of various types of disasters. This aligns with Çalışkan and Üner (2021), who suggest that by using this model, practices specific to disaster phases can be identified and supported within the community.

The effectiveness of disaster literacy can also be explained through the dual coding theory (Paivio, 2014), which posits that combining verbal and visual representations in learning can enhance information processing. The teaching materials developed in this study use illustrations, graphics, and disaster simulations, which have been empirically proven to strengthen students' understanding of abstract concepts in science (Septikasari et al., 2024b). Similar to Sugiyanto et al. (2024), this shows that visual media in disaster-based learning can enhance students' disaster literacy skills. Farzanegan et al. (2024) discussed the effectiveness of a special disaster training program aimed primarily at low-income households in enhancing educational literacy.

The creation of disaster mitigation-based teaching materials for physics learning has shown great promise in enriching the educational process. These teaching materials are intended not only to convey physics concepts effectively but also to enhance students' understanding of the practical applications of physics in disaster mitigation. Students can better connect the theories they have learned with natural phenomena by incorporating real disaster cases and interactive simulations, which facilitate a more in-depth and comprehensive learning experience (Ferdiansyah et al., 2021; Hasnawiyah & Maslena, 2024). In addition, the use of interactive media, such as simulations and multimedia content, has been shown to enhance students' understanding of scientific concepts while encouraging active learning (Yetti & Ahyanuardi, 2020Arjana & Suastra, 2022; Aprilyawati & Umam, 2023). The use of educational technology in electronic modules, such as Flip PDF Professional, not only increases accessibility and flexibility in learning but also facilitates the effective instillation of disaster values.

This is important because increasing students' disaster awareness involves not only knowledge, but also the ability to prepare and respond appropriately when facing a disaster. Although this study shows the effectiveness of the developed teaching materials, some limitations still need to be considered. The scope of the study covers only two schools. These teaching materials not only strengthen the academic foundation but also equip students with essential disaster resilience skills, which are highly valuable in a disaster-prone country like Indonesia.

## CONCLUSION

The findings of this study demonstrate that physics teaching materials integrated with disaster mitigation are valid, practical, and effective in enhancing students' disaster literacy. The materials achieved high content validity (89.48%) and media validity (87.27%), both of which are categorized as very valid. Student responses (94.00%) also indicated strong practicality. Their effectiveness is supported by a significant difference in N-gain scores between the experimental and control groups, with moderate effect sizes (d = 0.62 and d = 0.66). These findings confirm that the teaching materials successfully address the research problem by enhancing both conceptual understanding and disaster preparedness. When implemented, they positively impact students' awareness, equipping them with knowledge and skills essential for disaster response. As a key result, this innovation positions physics education as a strategic platform for disaster literacy development. Further research is recommended across schools in different disaster-prone regions to assess broader applicability and contextual relevance.

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