Effectiveness of STEM-Based Disaster Preparedness Learning Integrated with Project-Based Learning (PjBL) in Enhancing Students' Critical Thinking Skills and Environmental Literacy

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Abstract – *This study aimed to examine the effectiveness of the Project-Based Learning (PjBL) model integrated with STEM-based disaster preparedness learning in improving students' critical thinking skills and environmental literacy, as well as to investigate students' responses to learning the topic of Earth's Structure and Its Development. A quasi-experimental method with a nonequivalent control group design was employed. The sample consisted of 56 seventh-grade students from SMPN 1 Semarang, including 28 students in the experimental group (Class VIIIC), who received PjBL integrated with STEM-based disaster preparedness learning, and 28 students in the control group (Class VIIIB), who were taught using the Discovery Learning model. Critical thinking skills were assessed using essay tests based on the FRISCO framework, whereas environmental literacy and students' responses were measured using questionnaires. Data were analyzed using the Shapiro–Wilk normality test, normalized gain (N-gain) analysis, paired-samples t-test, and descriptive statistics. The results showed that students in the experimental group achieved greater improvement in critical thinking skills than those in the control group, with N-gain scores of 0.64 and 0.37, respectively, both categorized as moderate. The paired-samples t-test revealed a statistically significant improvement following the intervention ($p < 0.001$). The experimental group also demonstrated higher environmental literacy across the dimensions of knowledge, cognitive skills, attitudes, and behavior. Furthermore, students responded positively to the learning activities, with a practicality score of 85.53%, categorized as very practical. These findings indicate that integrating Project-Based Learning with STEM-based disaster preparedness learning is effective in enhancing students' critical thinking skills and environmental literacy on the topic of Earth's Structure and Its Development.*

Keywords*: Project Based Learning (PjBL); STEM-Based Disaster Preparedness Learning; critical thinking skills; environmental literacy; earthquake disaster mitigation.*

INTRODUCTION

Education in Indonesia plays a pivotal role in fostering disaster-resilient communities, particularly given the country's high vulnerability to natural hazards. Geographically, Indonesia is situated along the Pacific Ring of Fire at the convergence of three major tectonic plates: the Pacific, Indo-Australian, and Eurasian plates. This geological setting makes the country highly susceptible to a wide range of natural disasters, including earthquakes, tsunamis, volcanic eruptions, floods, and landslides, which often result in loss of life, environmental degradation, economic damage, and various social and public health challenges (Hutagalung et al., 2022). Consequently, Indonesia is recognized as one of the countries with the highest levels of disaster risk and a relatively high frequency of disaster events (Salsabila & Dinda, 2021).

Among these hazards, earthquakes are one of the most destructive. Beyond causing extensive damage to infrastructure, earthquakes disrupt the continuity of educational and healthcare services. According to the Ministry of Education and Culture (Kemendikbud, 2015), earthquakes that occurred in Aceh, West Sumatra, West

Java, Mentawai, North Lombok, Central Aceh, and Bener Meriah between 2004 and 2013 damaged approximately 5,186 school buildings. In addition to material losses, earthquakes occurring during school hours have resulted in injuries and fatalities among students. These circumstances highlight the urgent need to strengthen disaster risk reduction efforts by promoting disaster preparedness from an early age through formal education.

Disaster preparedness is a fundamental component of disaster risk reduction, as it plays a crucial role in minimizing casualties and mitigating the impacts of disasters. Knowledge is widely recognized as a key determinant of preparedness because it shapes individuals' awareness, concern, and capacity to take appropriate preventive actions before disasters occur (Hermawan, 2022). Therefore, fostering a culture of disaster preparedness should be pursued through systematic and continuous educational efforts beginning at the school level (Kamaruddin, 2025). In this context, teachers serve as key agents of disaster education and are expected to possess the competencies required to integrate disaster mitigation into science instruction (Hermawan & Wardhani, 2022). Likewise, Johan (2021) emphasized the importance of strengthening teachers' professional capacity to incorporate disaster mitigation into classroom learning, particularly in disaster-prone regions.

In addition to disaster preparedness, students also need to develop environmental literacy. Environmental literacy encompasses the ability to understand environmental concepts, identify and analyze environmental issues, and make informed decisions that support environmental sustainability (Pertiwi et al., 2024). These competencies enable students to recognize the interrelationships among human activities, environmental change, and disaster occurrence, thereby contributing to greater preparedness for future disasters (Alfyananda et al., 2024). Nevertheless, environmental literacy among the Indonesian population remains relatively low (Ningsih et al., 2024), which has contributed to limited public awareness and concern for environmental conservation (Santoso et al., 2021). Strengthening environmental literacy is therefore essential not only for fostering environmental responsibility but also for enhancing students' understanding of disaster risks and mitigation strategies (Anwar et al., 2024).

The development of environmental literacy and disaster preparedness is closely linked to students' critical thinking skills. Critical thinking enables learners to analyze information objectively, evaluate available evidence, and make reasoned decisions based on scientific evidence (Satria et al., 2024). Within the context of disaster education, these skills help students understand the relationships between environmental conditions and disaster risks, allowing them to determine appropriate mitigation strategies (Fauziah et al., 2024; Sigit et al., 2024). Accordingly, critical thinking serves as a fundamental foundation for developing both environmental literacy and disaster preparedness among students (Yanti et al., 2025).

The need to strengthen critical thinking, environmental literacy, and disaster preparedness calls for instructional approaches that actively engage students in contextual, inquiry-driven, and authentic problem-solving experiences. One promising approach is Project-Based Learning (PjBL) integrated with Science, Technology, Engineering, and Mathematics (STEM). STEM-integrated PjBL is well aligned with the implementation of the Merdeka Curriculum because it connects

scientific concepts with authentic problems encountered in everyday life (Setyawan, 2024). Through this approach, students are encouraged not only to acquire scientific knowledge but also to investigate real-world problems, design practical solutions, foster creativity, and apply their knowledge collaboratively through project-based activities. Such learning experiences have the potential to enhance critical thinking, improve environmental literacy, and strengthen disaster preparedness in meaningful ways. Furthermore, previous studies have shown that PjBL integrated with STEM can significantly improve students' motivation and engagement in learning (Ridha et al., 2022).

Research on STEM-based learning within the context of disaster education has expanded considerably in recent years. Arwin et al. (2024), for example, developed STEM-Based Digital Disaster Learning, which integrates digital technology with STEM principles to improve disaster adaptation skills among elementary school students. Their findings demonstrated improvements in both disaster preparedness and adaptive capacity. However, the study was limited to elementary education and did not explicitly investigate critical thinking or environmental literacy as higher-order cognitive competencies.

Similarly, Sampurno et al. (2022) developed a PBL-STEM-based electronic worksheet to enhance disaster literacy among junior secondary school students. Their findings indicated that technology-assisted PBL-STEM effectively improved students' disaster literacy. Nevertheless, the study focused exclusively on disaster literacy without simultaneously examining environmental literacy and critical thinking within an integrated instructional framework.

Overall, previous studies have demonstrated that integrating PjBL or PBL with STEM in disaster education can positively influence students' competencies. However, most existing research remains fragmented, either by focusing on a single learning outcome or by examining only one aspect of twenty-first-century competencies. In particular, limited attention has been given to the simultaneous development of critical thinking skills and environmental literacy within a comprehensive disaster preparedness learning framework.

Therefore, the novelty of this study lies in the implementation of a Project-Based Learning (PjBL) model integrated with STEM-Based Disaster Preparedness Learning in teaching the topic of Earth's Structure and Its Development at the junior secondary school level. Furthermore, this study simultaneously examines its effectiveness in improving students' critical thinking skills and environmental literacy, two interconnected competencies that are essential for developing disaster preparedness in the twenty-first century.

RESEARCH METHODS

This study employed a quantitative approach using a quasi-experimental design with a nonequivalent control group. The research was conducted in March and April 2026 at SMP Negeri 1 Semarang. Class VIIIC served as the experimental group, while Class VIIIB served as the control group. The control group was taught using the Discovery Learning model, whereas the experimental group received instruction through the Project-Based Learning (PjBL) model integrated with STEM-Based Disaster Preparedness Learning. Both groups completed pretests and posttests to assess their critical thinking skills before and after the intervention.

Students' critical thinking skills were assessed using a five-item essay test developed based on the FRISCO indicators. In addition, environmental literacy and students' responses to the learning process were measured using questionnaires. All research instruments were validated by experts prior to data collection. Content validity was evaluated using Aiken's V, yielding coefficients ranging from 0.857 to 1.000, with two items categorized as having high validity and nine items classified as having very high validity. These results indicate that all instruments possessed strong content validity and were appropriate for use in this study. Instrument reliability was assessed using Cronbach's alpha, resulting in a coefficient of 0.694, indicating acceptable internal consistency.

The effectiveness of the Project-Based Learning (PjBL) model integrated with STEM-Based Disaster Preparedness Learning in improving students' critical thinking skills and environmental literacy on the topic of *Earth's Structure and Its Development* was evaluated through quantitative data analysis. Critical thinking data were obtained from the pretest and posttest administered before and after the instructional intervention. Prior to hypothesis testing, the data were subjected to normality and homogeneity tests to ensure that the assumptions for parametric analysis were satisfied. The normalized gain (N-gain) score was calculated to determine the extent of improvement in students' critical thinking skills following the intervention. Subsequently, a paired-samples *t*-test was conducted to examine differences between the pretest and posttest scores within each group.

In addition to the critical thinking assessment, data on students' environmental literacy and their responses to the learning activities were collected through questionnaires. These data were analyzed descriptively using percentage analysis to provide an overview of students' environmental literacy levels and their perceptions of the learning experience following the implementation of the Project-Based Learning (PjBL) model integrated with STEM-Based Disaster Preparedness Learning. The findings are presented as percentages for each indicator and interpreted according to the established assessment criteria. This analysis was intended to evaluate students' environmental literacy while also providing insights into their acceptance of and responses to the implemented instructional model.

RESULTS AND DISCUSSION

Results

The normality of the pretest and posttest data for both the experimental and control groups was assessed using the Shapiro–Wilk test in SPSS. The results showed that the significance values for the pretest were 0.536 and 0.113 for the experimental and control groups, respectively, while the corresponding significance values for the posttest were 0.126 and 0.118. Since all significance values exceeded 0.05, the data were considered to be normally distributed.

Following confirmation of normality, the data were analyzed to determine the improvement in students' critical thinking skills using the normalized gain (N-gain) score. The results of the N-gain analysis are presented in Table **1**.

Table 1. N-Gain Calculation Results

Experimental		**Control**	
Pretest	Posttest	Pretest	Posttest
44.11	79.29	39.82	61.96
N-Gain: 0.64 (Moderate)		**N-Gain: 0.37 (Low)**	

Based on the N-gain analysis, the experimental group demonstrated a greater

improvement in learning outcomes than the control group. However, the N-gain score only reflects the magnitude of improvement and does not determine whether the observed difference is statistically significant. Therefore, hypothesis testing was conducted using a paired-samples *t*-test to determine whether the improvement in the experimental group was statistically significant.

The results of the paired-samples *t*-test yielded a *t* value of 25.70 with a significance value (*p*) of < 0.001. Since the significance value was lower than 0.05, a statistically significant difference was found between the students' pretest and posttest scores. These findings indicate that the implementation of the Project-Based Learning (PjBL) model integrated with STEM-Based Disaster Preparedness Learning significantly improved students' critical thinking skills on the topic of *Earth's Structure and Its Development*.

The results of the environmental literacy questionnaire for both the experimental and control groups are presented in Figure 1.

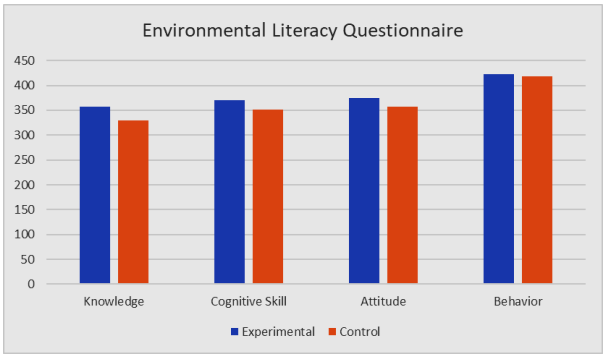

Figure 1. Percentage Scores of the Environmental Literacy Questionnaire

The results indicate that students in the experimental group achieved higher scores than those in the control group across all environmental literacy indicators, namely knowledge, cognitive skills, attitudes, and behavior. The behavior indicator recorded the highest scores in both groups, with scores of 423 (94.42%) in the experimental group and 418 (93.30%) in the control group. These findings suggest that students had already developed positive behavioral tendencies toward environmentally responsible practices.

Table 2. Environmental Literacy Questionnaire Scores

Indicator	Experimental Class		Control Class	
Knowledge	357	79,69%	329	73,44%
Cognitive Skill	370	82,59%	352	78,57%
Attitude	375	83,71%	357	79,69%
Behavior	423	94,42%	418	93,30%

In contrast, the knowledge indicator yielded the lowest scores in both groups, with scores of 357 (79.69%) for the experimental group and 329 (73.44%) for the control group. Nevertheless, the experimental group consistently outperformed the control group. Similarly, higher scores were observed in the experimental group for both the cognitive skills and attitudes indicators, indicating that these students demonstrated stronger abilities to analyze environmental issues and exhibited more positive attitudes toward environmental conservation.

Overall, the findings suggest that the implementation of the Project-Based Learning (PjBL) model integrated with STEM-Based Disaster Preparedness Learning effectively promoted students' environmental literacy, as reflected by consistently higher scores across all indicators compared with those of the control group.

Students' responses to the implementation of the Project-Based Learning (PjBL) model integrated with STEM-Based Disaster Preparedness Learning were collected using a response questionnaire administered after the completion of the instructional intervention

in the experimental group. The results are presented in Figure 2.

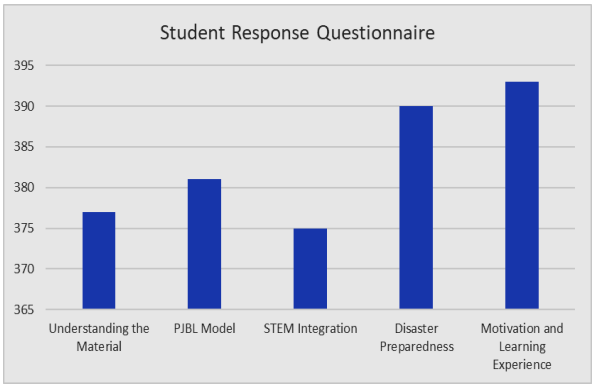

Figure 2. Percentage Scores of the Student Response Question

Based on the results of the student response questionnaire, the experimental group obtained a mean score of 3.42, corresponding to an overall percentage of 85.53%, which falls within the very practical category. All evaluated indicators, including interest and engagement, participation in learning activities, understanding of the learning materials, environmental attitudes, and disaster mitigation awareness, were also classified as very practical. These findings indicate that students responded positively to the implementation of the Project-Based Learning (PjBL) model integrated with STEM-Based Disaster Preparedness Learning.

Discussion

Earth's Structure and Its Development had a positive effect on students' critical thinking skills. Project-Based Learning places projects at the center of the learning process, actively engaging students in investigation, problem-solving, and the development of products that address authentic real-world situations (Thomas, 2000; Markham, 2011).

The findings indicate that this instructional approach was more effective than the Discovery Learning model in enhancing students' critical thinking skills. The N-gain analysis revealed that the experimental group achieved an N-gain score of 0.64 (moderate category), whereas the control group obtained an N-gain score of 0.37 (low category). These findings were further supported by the paired-samples *t*-test, which yielded a t value of 25.70 with a significance level of $p < 0.001$, indicating a statistically significant difference between the pretest and posttest scores of the experimental group.

The improvement in students' critical thinking skills can be attributed to the implementation of the PjBL learning phases, which encouraged students to identify earthquake-related risks within their school environment, design digital evacuation maps, collect and analyze relevant data, and present and reflect on their project outcomes. Through these activities, students developed the ability to analyze information, construct evidence-based arguments, evaluate alternative solutions, and make logical decisions.

These findings are consistent with those of Kokotsaki, Menzies, and Wiggins (2016), who reported that Project-Based Learning effectively promotes higher-order thinking skills through investigation, collaboration, and authentic problem-solving activities. Likewise, Bell (2010) argued that project-based learning enhances critical thinking, communication, and decision-making skills by providing meaningful and contextual learning experiences.

The effectiveness of the PjBL model in this study was further strengthened by its integration with STEM-Based Disaster Preparedness Learning. The science component focused on understanding the Earth's structure and the mechanisms of earthquakes. Technology was incorporated through the use of Google Maps and Canva. The engineering component involved designing evacuation routes and assembly

points, while mathematics was applied through distance measurement and map-scale calculations. This integrated approach enabled students to connect scientific concepts with practical disaster mitigation strategies. According to the National Science Teachers Association (2011), STEM education encourages students to solve contextual problems, thereby fostering critical thinking and problem-solving skills.

Students' critical thinking skills were analyzed using the FRISCO framework. Regarding the focus indicator, students were able to identify the main issues related to the Earth's structure and earthquake hazards through the student worksheets and guiding questions. This finding supports Ennis (1993), who argued that critical thinking begins with the ability to clearly define and focus on a problem. The reason indicator was demonstrated when students provided scientific explanations for the causes of earthquakes and justified the selection of evacuation routes based on the evidence they had collected. The inference indicator emerged when students drew conclusions from their analyses and related their understanding of the Earth's structure to disaster mitigation efforts. These findings suggest that students not only understood the information presented but were also able to interpret evidence and formulate logical conclusions based on that evidence (Ennis, 1993).

Regarding the situation indicator, students' critical thinking skills developed through direct engagement with authentic contexts within the school environment. The situation dimension refers to the ability to use relevant information derived from data, reports, principles, evidence, judgments, beliefs, opinions, concepts, descriptions, questions, or other forms of representation when addressing a problem (Setiana & Purwoko, 2020). In this study, the digital evacuation map project required students to identify real-world conditions, including evacuation routes, assembly points, and potential hazards. This finding is consistent with the STEM approach, which emphasizes contextual learning through authentic real-world problems as a means of developing critical thinking and problem-solving skills (National Science Teachers Association, 2011).

The clarity indicator was reflected in students' ability to communicate the outcomes of group discussions, document their responses in the student worksheets, and present their project products. These activities provided opportunities for students to express their ideas clearly, logically, and systematically. According to Ennis (1993), the ability to explain and defend one's reasoning is a fundamental component of critical thinking. Meanwhile, the overview indicator developed during the project reflection and evaluation stages, where students reviewed both the learning process and the outcomes of their work. Such reflective activities demonstrate metacognitive skills that enable students to critically evaluate their learning experiences (Dewey, 1933).

Through the digital evacuation map project, students actively analyzed environmental conditions, evaluated alternative evacuation routes, and selected appropriate solutions based on the collected data. These activities strengthened their ability to identify problems, analyze information, draw conclusions, and make informed decisions. Furthermore, connecting learning activities with disaster preparedness made the instructional content more meaningful, thereby increasing students' engagement and motivation. As a result, students in the experimental group demonstrated greater improvements in

critical thinking skills than those in the Discovery Learning group.

According to Bruner (1961), Discovery Learning emphasizes the independent construction of knowledge through observation, classification, and concept discovery. This instructional model is effective in helping students develop conceptual understanding through exploration and inquiry. In the present study, students in the control group also demonstrated improvements in critical thinking skills, indicating that Discovery Learning contributed positively to their cognitive development. However, the implementation of Discovery Learning in this study primarily focused on discovering concepts related to the Earth's structure and earthquakes without requiring students to produce authentic products applicable to real-life situations. Bell (2010) argued that project-based activities leading to tangible products provide richer opportunities for developing problem-solving, decision-making, and critical thinking skills. Unlike the experimental group, which designed digital evacuation maps, students in the control group had fewer opportunities to develop practical solutions, evaluate alternative strategies, and assess their work based on actual environmental conditions. Consequently, their engagement in contextual problem-solving and the application of scientific concepts was less extensive, resulting in lower gains in critical thinking skills than those achieved by the experimental group.

Overall, these findings indicate that the implementation of the Project-Based Learning (PjBL) model integrated with STEM-Based Disaster Preparedness Learning through a digital earthquake evacuation map project significantly enhanced students' critical thinking skills. More broadly, STEM-integrated project-based learning provided students with contextual, collaborative, and problem-oriented learning experiences. Such experiences not only promoted the development of critical thinking but also supported environmental literacy by engaging students in identifying environmental issues, analyzing disaster risks, and designing practical mitigation strategies applicable within the school environment.

The results of the environmental literacy questionnaire further showed that the experimental group achieved higher scores than the control group across all four indicators: knowledge, cognitive skills, attitudes, and behavior. These findings indicate that the integration of Project-Based Learning with STEM-Based Disaster Preparedness Learning was more effective in fostering students' environmental literacy than the instructional approach implemented in the control group.

For the knowledge indicator, the experimental group obtained a score of 357, whereas the control group scored 329. Regarding cognitive skills, students demonstrated their ability to analyze and evaluate environmental information by identifying earthquake hazards, selecting safe assembly points, and designing effective evacuation routes. These competencies developed through project activities that required students to apply higher-order thinking skills. This finding is consistent with the National Science Teachers Association (2011), which emphasized that STEM education promotes critical thinking and problem-solving through authentic, real-world contexts.

The attitudes indicator developed through classroom discussions on the impacts of earthquakes and the importance of disaster mitigation. Students demonstrated greater awareness of personal

safety and environmental responsibility while determining evacuation routes and designing digital evacuation maps. These findings support Stapp's (1969) view that environmental literacy encompasses not only knowledge but also attitudes and concern for the environment. Similarly, Garaika and Sugandini (2021) argued that positive environmental attitudes contribute to the development of environmentally responsible behavior.

Among all indicators, behavior achieved the highest scores in both groups. This finding indicates that students were able not only to understand environmental concepts and analyze disaster-related issues but also to translate that understanding into practical action. Through observations of the school environment and the development of digital evacuation maps, students identified building conditions, evacuation access points, and safe assembly areas to improve disaster preparedness. These activities illustrate the practical application of environmental literacy through actions aimed at reducing disaster risk within the school environment. This finding is consistent with Orr (1992), who argued that environmentally literate individuals are capable of taking responsible action to protect and sustain the environment. Likewise, Srivastava (2024) reported that environmental literacy has a significant influence on students' environmentally responsible behavior.

The superior performance of the experimental group can be attributed to the characteristics of project-based learning, which actively engages students in solving authentic problems. In this study, students designed digital earthquake evacuation maps for their school environment. Through this project, they not only learned theoretical concepts related to the Earth's structure and earthquakes but also connected these concepts to local environmental conditions and practical disaster mitigation strategies. Such contextual learning experiences facilitated the development of students' environmental knowledge, cognitive skills, attitudes, and responsible behaviors.

In contrast, students in the control group, who learned through the Discovery Learning model, primarily focused on independently discovering scientific concepts, with limited opportunities to relate those concepts to authentic environmental issues or to develop practical solutions. Consequently, learning was centered more on conceptual understanding than on applying knowledge to analyze environmental conditions and design disaster mitigation strategies. Although both groups demonstrated good levels of environmental literacy, the experimental group consistently outperformed the control group across all indicators. These findings suggest that the Project-Based Learning (PjBL) model integrated with STEM-Based Disaster Preparedness Learning is more effective than Discovery Learning in promoting students' environmental literacy on the topic of *Earth's Structure and Its Development*.

These meaningful learning experiences were also reflected in students' responses to the instructional intervention. Overall, students responded very positively to the implementation of the Project-Based Learning (PjBL) model integrated with STEM-Based Disaster Preparedness Learning, as indicated by an overall percentage score of 85.53%, which falls within the very practical category, and a mean score of 3.42. These findings suggest that the instructional approach created an engaging learning environment, encouraged active student participation, and facilitated a deeper understanding of the topic *Earth's Structure and Its Development*. This positive

response can be explained from a constructivist perspective, in which students construct knowledge through meaningful and engaging learning experiences. In this context, the integration of PjBL with STEM provided students with opportunities to actively engage in solving authentic real-world problems, thereby enhancing their motivation to learn (Anazifa & Djukri, 2021; National Science Teachers Association, 2018).

The understanding of learning materials indicator achieved a percentage score of 84.15%, indicating that the instructional model effectively facilitated students' conceptual understanding of the Earth's structure. This finding is consistent with previous studies showing that project-based learning enhances conceptual understanding by actively engaging students in constructing knowledge through direct learning experiences (Anazifa & Djukri, 2021). The PjBL implementation indicator obtained a percentage score of 80.78%, demonstrating that students responded positively to the project-based learning approach. Previous research has shown that PjBL enhances students' engagement, interest, and learning motivation by providing authentic, problem-based learning experiences (Kokotsaki et al., 2016).

The STEM integration indicator received a percentage score of 79.81%, which was classified as positive. This finding indicates that integrating science, technology, engineering, and mathematics into the learning process provided students with engaging, contextual, and application-oriented learning experiences. This result is consistent with Bell (2010), who reported that STEM-based learning enhances student engagement and helps learners connect academic concepts with real-world problems.

For the disaster preparedness indicator, a percentage score of 88.77% was obtained, reflecting a very positive student response to disaster preparedness-based learning. This result suggests that integrating disaster-related content into classroom instruction effectively increased students' awareness and understanding of the importance of disaster preparedness. These findings are in line with those of Septikasari and Ayriza (2020), who reported that disaster mitigation education delivered through active learning strategies improves students' knowledge, awareness, and preparedness for potential disasters in their surrounding environment.

The motivation and learning experience indicator achieved the highest percentage score (90.13%), which also fell within the very positive category. This finding indicates that the instructional model created enjoyable, challenging, and meaningful learning experiences for students. Active involvement in project activities encouraged students to participate more fully throughout the learning process. This finding is supported by Han, Capraro, and Capraro (2021), who argued that STEM-integrated project-based learning enhances students' intrinsic motivation by providing opportunities to solve authentic problems through relevant and meaningful activities.

Overall, the questionnaire results demonstrate that students responded very positively to the implementation of the Project-Based Learning (PjBL) model integrated with STEM-Based Disaster Preparedness Learning. The instructional model successfully created an active, collaborative, contextual, and meaningful learning environment that was closely connected to students' everyday experiences. The high level of student acceptance was also consistent with the observed improvements in critical thinking skills and

environmental literacy. Taken together, these findings indicate that the Project-Based Learning (PjBL) model integrated with STEM-Based Disaster Preparedness Learning is not only effective in enhancing students' critical thinking skills and environmental literacy but is also highly accepted by students, making it a practical and feasible instructional alternative for teaching the topic of *Earth's Structure and Its Development*.

CONCLUSION

The findings of this study demonstrate that the implementation of the Project-Based Learning (PjBL) model integrated with STEM-Based Disaster Preparedness Learning in teaching *Earth's Structure and Its Development* was more effective than the Discovery Learning model in improving students' critical thinking skills. This conclusion is supported by the results of the N-gain analysis and hypothesis testing, which revealed a statistically significant difference in learning gains between the experimental and control groups. By situating project-based learning within the context of disaster preparedness, students were encouraged to identify real-world problems, design alternative solutions, and evaluate the effectiveness of their proposed strategies. These learning processes were facilitated through the development of digital earthquake evacuation maps, requiring students to apply scientific concepts to authentic problems encountered in the school environment.

In addition to enhancing critical thinking skills, students' participation in the project had a positive impact on the development of their environmental literacy. The questionnaire results showed that students in the experimental group achieved higher scores than those in the control group across all dimensions of environmental literacy, including knowledge, cognitive skills, attitudes, and behavior. These findings indicate that integrating the STEM approach with disaster preparedness learning not only improved students' understanding of environmental issues and disaster risks but also fostered greater environmental awareness and responsible behaviors that support disaster risk reduction.

The effectiveness of the instructional model was further reflected in the highly positive responses provided by the students. They perceived the learning activities as engaging, challenging, and relevant because they were directly connected to real conditions within the school environment through the digital earthquake evacuation map project. These positive responses suggest that project-based learning enhanced students' motivation, active participation, and enthusiasm throughout the learning process.

Overall, the Project-Based Learning (PjBL) model integrated with STEM-Based Disaster Preparedness Learning represents an effective instructional approach for science education, particularly in fostering students' critical thinking skills and environmental literacy. Future research is recommended to examine the effectiveness of this model across different science topics, involve larger and more diverse samples, and incorporate a wider variety of project activities to further evaluate its applicability and educational impact.

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