

## Science, Technology, Engineering, Mathematics - Engineering Design Process with Earthquake-Proof House Project to improve students' STEM Literacy

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**Abstract.** Students' low STEM literacy level is a major challenge in 21st-century education, particularly in preparing students to face real-world problems. This study aims to examine the effectiveness of the STEM engineering design process (STEM-EDP) approach in enhancing students' STEM literacy in the context of earthquake disaster mitigation. A quasi-experimental method was used with 50 eighth-grade students divided into an experimental group (28 students) and a control group (22 students). The experimental group applied the STEM-EDP approach, while the control group received conventional instruction. The results show that the STEM-EDP approach significantly improved students' STEM literacy, with an average N-Gain of 0.33 (moderate category), compared to 0.23 (low category) in the control group. These findings indicate that the STEM-EDP approach enhances STEM literacy more effectively than conventional methods. This approach is relevant for addressing 21st-century challenges by integrating STEM literacy into meaningful learning experiences, particularly within the context of authentic, project-based education.

**Keywords:** STEM-EDP, STEM literacy, disaster mitigation

## Introduction

Various educational challenges include students' readiness to face real-life situations in their communities (Amelia & Santoso, 2021; Siregar et al., 2024). School teaching materials often lack real-world problems and fail to integrate science, technology, engineering, and mathematics (STEM) concepts comprehensively (Niam & Asikin, 2020). Additionally, students' new literacy skills, including data, technology, and human literacy, remain low, with an average literacy score of 43.41, categorized as poor. To prepare students for life, science education is crucial in developing critical thinking, problem-solving, and innovation skills, essential for adapting to technological advancements (Silber-Varod et al., 2019). Students' low scientific literacy and creativity indicate the need for innovative learning approaches. STEM learning supports creative thinking and enhances scientific literacy (Busyairi et al., 2023). According to Lau et al. (2024), STEM fosters active

learning and helps students acquire essential workplace skills (Amelia & Santoso, 2021). By engaging students in problem-solving and integrating knowledge, STEM enhances competencies for a rapidly advancing world (Newton & Tonelli, 2020).

STEM learning trains students to think critically and solve real-world problems creatively, meeting 21st-century demands. Research highlights that STEM enhances high-order thinking, science process skills, problem-solving abilities, and 4C skills (Astuti et al., 2021; Husein, 2016; Triana et al., 2020; Wardani et al., 2019). Problem-based STEM learning helps students address real-life challenges and promotes collaboration in finding creative solutions (Al Ali, 2024). Students develop academic understanding and essential interpersonal skills by engaging in group projects. Low literacy levels in science, technology, engineering, and mathematics present major educational challenges (González-Peña et al., 2021). STEM literacy ensures that students grasp theoretical concepts and develop critical thinking and problem-solving skills applicable to real-world issues. Research indicates that STEM project implementation in inclusive high schools fosters literacy development through collaborative, challenge-based learning (Stehle et al., 2019). Additionally, an integrated STEM and project-based learning (PjBL) curriculum prepares students for future technological challenges (Falloon et al., 2020).

Indonesia's low PISA rankings highlight the urgency of improving STEM literacy. In 2018, Indonesia ranked 70th out of 78 countries in science literacy, with an average score of 379, demonstrating students' weak understanding and application of science concepts. Studies show that project-based STEM learning significantly improves students' science literacy (Kartini et al., 2021). Further research is needed to design effective educational strategies that enhance STEM literacy and prepare students for an increasingly technology-driven society. STEM-EDP learning effectively enhances STEM literacy by providing real-world project experiences. This approach encourages teamwork, problem-solving, and innovative thinking, allowing students to connect theory with practical applications. Research indicates that STEM PjBL enhances problem-solving and creativity, even using waste materials (Baran et al., 2021). Problem-based STEM learning fosters real-world engagement, builds self-confidence, and strengthens collaboration skills (Al Ali, 2024; Stehle & Peters-Burton, 2019).

Project-based STEM learning has been shown to improve self-efficacy, logical reasoning, and teamwork. For example, physics mechanics studies demonstrate enhanced student self-efficacy (Samsudin et al., 2020), while robotics projects improve logical thinking and collaboration (Hsu & Tsai, 2022). Additionally, integrating STEM into sound concept learning at the elementary level significantly increases conceptual understanding and teamwork (Dedetürk et al., 2021). These findings affirm that STEM enhances academic performance and develops crucial interpersonal skills for future success. Our research focuses on STEM-EDP for earthquake disaster mitigation, aligning with sustainable development goals number 11 and 13 (Leicht, 2018; Velázquez & Rivas, 2020). Unlike previous studies that explored flood disaster mitigation (Zulfiya et al., 2023) or employed simpler learning models (Kartini et al., 2021) this study uses a more detailed eight-stage learning syntax, covering problem definition, data collection, planning, prototyping, testing, evaluation, redesign, and communication. This approach provides a structured framework for STEM-EDP disaster mitigation projects, enhancing STEM literacy through earthquake-resistant housing design. Thus, this study aims to evaluate the impact of STEM-EDP on students' STEM literacy in earthquake disaster mitigation.

## **Methods**

This study employs a quasi-experimental approach to examine the effectiveness of STEM-EDP in enhancing students' STEM literacy. A quantitative method is applied to

measure changes in both variables. The research design follows the framework proposed by Creswell (2019), as outlined in Table 1. The study involves pretests and post-tests for the experimental and control groups, with the experimental group receiving STEM-EDP-based learning while the control group follows conventional instruction.

**Table 1.** Research design

Group	Pretest	Treatment	Post-test
Experiment	O <sub>1</sub>	X	O <sub>2</sub>
Control	O <sub>1</sub>	-	O <sub>2</sub>

The participants consist of 50 eighth-grade students from SMP "X," divided into an experimental group (28 students) and a control group (22 students). The experimental group engages in STEM-EDP with a disaster mitigation theme, while the control group undergoes conventional learning. The distribution of participants is shown in Table 2.

**Table 2.** Participant

Class	Man	Woman	Total
Control	11	11	22
Experiment	14	14	28
Total	25	25	50

STEM literacy is assessed through an objective multiple-choice test that evaluates students' understanding of science, technology, engineering, and mathematics concepts and their ability to apply these in real-world contexts. The test follows the validated instrument developed (Kartini et al., 2021) aligns with four aspects of STEM literacy: scientific, technological, engineering, and mathematical literacy. The indicators for STEM literacy assessment are presented in Table 3.

**Table 3.** STEM literacy indicator

Indicator	Information
Scientific literacy	The ability to understand and apply concepts and processes in science to make decisions related to the environment, health, economics, and other issues requiring scientific knowledge.
Technology literacy	The ability to understand how technology is created, shapes, and is influenced by society and how technology is used to solve everyday problems.
Technical literacy	The ability to apply scientific and mathematical principles systematically and creatively for practical purposes, such as designing, producing, and operating efficient and economical structures, machines, processes, and systems.
Mathematical literacy	The ability to recognize, understand, and engage with mathematics and to make good decisions about the role of mathematics in personal, professional, and social life, and as a constructive, caring, and reflective citizen.

Data analysis is conducted using SPSS statistical procedures. A normality test determines the data distribution, followed by a Wilcoxon signed rank test for non-normally distributed data to assess significant differences in STEM literacy between groups. Additionally, the Mann-Whitney U test examines correlations between variables in both classes, offering insights into the impact of STEM-EDP learning on students' skills.

N-Gain analysis is performed on pretest and post-test results to measure learning effectiveness. The findings indicate a significantly higher average N-Gain in the experimental group than the control group, demonstrating that STEM-EDP-based learning is more effective in enhancing STEM literacy than conventional methods. To calculate the N-Gain score, use formula (1).

$$N\text{-Gain} = \left( \frac{\text{posttest score} - \text{pretest score}}{\text{maximum score} - \text{pretest score}} \right) \quad (1)$$

The study applies the STEM-EDP learning strategy following Bamberger & Cahill's (2013) framework, which includes defining problems, gathering information, planning, building, testing, evaluating, redesigning, and communicating. The learning strategy is presented in Table 4.

**Table 4.** STEM EDP syntax

No	Indicator	Information
1	Defining the problem	Students are asked to identify and define the problem
2	Gathering information	Students are asked to gather relevant information through scientific exploration.
3	Planning	Students are asked to design solutions to problems
4	Building	Students are asked to develop a prototype solution.
5	Testing	Testing is carried out on the building products
6	Evaluating	Evaluating test results
7	Redesigning	Students make improvements to product prototypes
8	Communicating	Students are asked to submit product results

(Source: Bamberger & Cahill, 2013)

## Results and Discussion

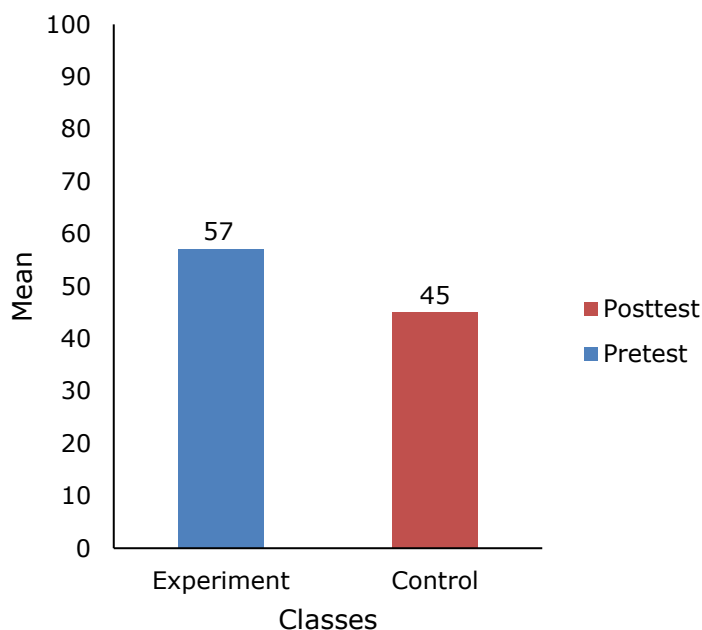
STEM-EDP-based learning aims to improve learning outcomes and 21st-century skills (Benek & Akcay, 2022; Stehle & Peters-Burton, 2019; Vistara et al., 2022), such as STEM literacy by engaging students in authentic projects relevant to everyday life. To evaluate the effectiveness of this approach, a study was conducted by comparing learning outcomes between an experimental class using the STEM-EDP strategy and a control class using conventional learning methods. Data obtained from the pretest and post-test in both classes provide an overview of the differences in learning outcomes and the influence of the applied learning approach. Descriptive statistics of the research results in STEM Literacy can be seen in Table 5.

**Table 5. Descriptive statistics of STEM literacy**

	N	Minimum	Maximum	Mean	Std. Deviation
Experiment Pretest	28	0	60	34.6429	12.31745
Posttest Experiment	28	40	80	57.5000	13.77733
Pretest Control	22	0	50	27.7273	11.51885
Posttest Control	22	30	60	45.0000	10.57850

Based on the data provided, students' STEM literacy was analyzed using the results of the pretest and post-test in the experimental and control groups. In the experimental group of 28 students, the pretest scores ranged from 0 to 60, with an average of 34.64 and a standard deviation of 12.32. After the intervention, the post-test scores of the experimental group increased significantly, with a range of 40 to 80, an average of 57.50, and a standard deviation of 13.78. Meanwhile, in the control group, consisting of 22 students, the pretest scores ranged from 0 to 50, with an average of 27.73 and a standard deviation of 11.52. After the intervention, the post-test scores of the control group also increased, although not as much as those of the experimental group, with a range of scores from 30 to 60, an average of 45.00, and a standard deviation of 10.58.

A comparison of pretest and post-test results shows that the intervention given to the experimental group is more effective in improving STEM literacy than the control group. This can be seen from the greater increase in the average value in the experimental group compared to the control group. To indicates that STEM-EDP-based learning improves average learning outcomes and provides greater opportunities for students to achieve optimal learning outcomes, as seen in Figure 1.



**Figure 1.** Comparison of mean scores between experimental and control classes

A normality test such as Kolmogorov-Smirnov or Shapiro-Wilk can be performed to check the normality of data on the STEM Literacy variable. This test determines whether the pretest and post-test data in the experimental and control groups are normally distributed. If the test's significance value (p-value) exceeds 0.05, then the data is normally distributed. Table 6 shows the data processing that has been done.

**Table 6.** STEM literacy normality test

Treatment	Kolmogorov-Smirnova			Shapiro Wilk		
	Statistics	df	Sig.	Statistics	df	Sig.
Pretest Experiment	0.210	28	0.003	0.904	28	0.015
Post-test Experiment	0.207	28	0.003	0.892	28	0.007

From the data obtained, it is known that the significance value is less than 0.005, so the data is considered not normally distributed. The analysis and data processing are continued with the Mann-Whitney Test to see the hypothesis. So, based on the results of the Mann-Whitney Test on the STEM literacy variable, Table 7 can be seen.

**Table 7.** Hypothesis testing

	STEM Literacy
Mann-Whitney U	161.000
Wilcoxon W	414.000
Z	-2.950
Asymp. Sig. (2-tailed)	0.003

From the data results, it was obtained that the significance value was 0.003 and less than 0.05. So, there is a significant difference in STEM literacy between the two groups tested, namely the control and experimental classes. This difference indicates that the intervention or treatment given to one of the groups impacts students' STEM literacy. Furthermore, a homogeneity test was conducted to ensure that the variance between the experimental and control groups was homogeneous in the pretest and post-test. If the significance value of the homogeneity test is greater than 0.05, then the assumption of homogeneity of variance is met. The results of the homogeneity test can be seen in Table 8. Based on the homogeneity test results with Levene's test, the significance value (Sig.) in all calculation methods (mean, median, median with adjusted df, and trimmed mean) is greater than 0.05. The Sig. value based on the mean is 0.126, and based on the median is 0.145. To show that the variance between groups is homogeneous because no significant difference exists between the groups tested. Thus, the assumption of homogeneity of variance is met.

**Table 8.** STEM literacy homogeneity test

	Levene Statistics	df1	df2	Sig.
Based on Mean	2.430	1	48	0.126
Based on Median	2.197	1	48	0.145
Based on the Median and with adjusted df	2.197	1	47.774	0.145
Based on trimmed mean	2.427	1	48	0.126

This study used N-gain analysis to evaluate the effectiveness of improving learning outcomes between the experimental and control classes. The N-gain test measures the extent to which students' understanding has increased after participating in learning by comparing the pretest and post-test scores. N-gain provides a clearer picture of the level of proportional improvement in learning outcomes, taking into account the initial conditions of the students. Higher N-gain values indicate a significant increase in understanding the material, while lower values reflect limited changes. The following analysis examines the N-gain results in both groups to assess the effectiveness of the learning strategies presented in Table 9.

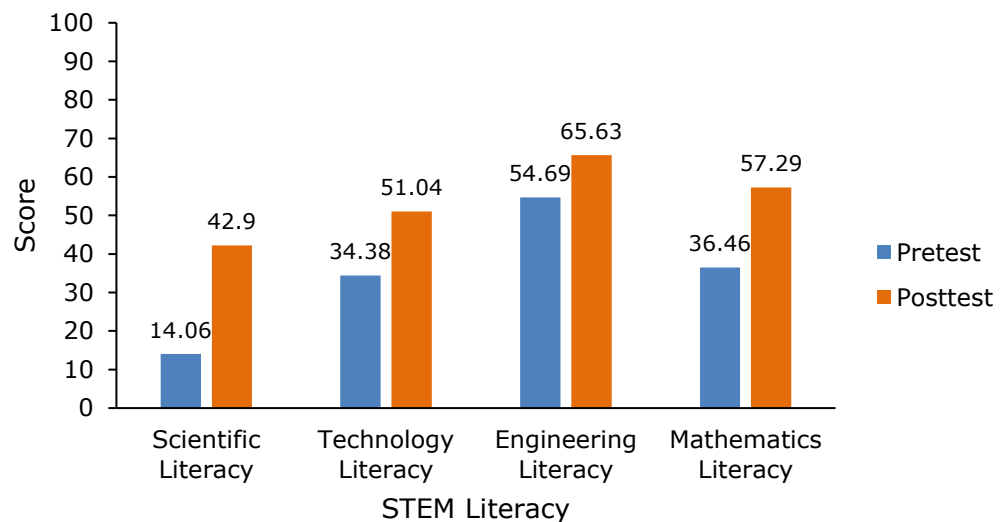
**Table 9.** N-Gain STEM literacy

	N	Minimum	Maximum	Mean
N-Gain Score Control	22	0.00	0.43	0.233
N-Gain Score Experiment	28	0.00	0.71	0.331

Based on the N-Gain STEM literacy data, the control group (N=22) had a minimum N-Gain score of 0.00 and a maximum of 0.43, with an average of 0.2330 and a standard deviation of 0.133. Meanwhile, the experimental group (N=28) had a minimum N-Gain score of 0.00 and a maximum of 0.71, with an average of 0.331 and a standard deviation of 0.237. The average N-Gain score of the experimental group (0.331) was higher than the control group (0.233), indicating that the increase in STEM literacy in the experimental group was greater than the control group. In addition, the larger standard deviation in the experimental group (0.237) compared to the control (0.133) indicates a higher variation in the increase in STEM literacy in the experimental group. Overall, with an N-Gain value of 0.331 in the experimental class indicating a moderate category, while an N-Gain value of 0.233 in the control class indicating a low category, these results indicate that the intervention or treatment applied to the experimental group had a more significant impact on increasing STEM literacy compared to the control group.

Then STEM literacy is the ability to understand and apply basic concepts in four main areas, namely STEM science literacy refers to understanding scientific concepts and processes that enable individuals to think critically about the world around them. Engineering literacy includes understanding the basic principles of designing and building systems and solving practical problems using engineering approaches. Technology literacy

refers to utilizing technological tools and systems in various contexts and understanding their impact on everyday life. Mathematics literacy teaches skills to apply mathematical concepts in solving real problems and logical and analytical thinking. These four indicators are interconnected and form the basis for developing 21st-century skills in an increasingly complex and technology-based world. The results of the STEM literacy indicators can be seen in Figure 2.



**Figure 2.** Mean score results in each aspect of students' STEM literacy

The pretest and post-test results showed significant improvements in students' STEM literacy. The pretest score of 14.06 in science literacy increased to 42.19 in the post-test, reflecting students' improved understanding of scientific concepts and CTS. In technology literacy, the pretest score of 34.38 increased to 51.04, indicating students' progress in understanding the use and impact of technology. Engineering literacy also showed a clear improvement, from a pretest score of 54.69 to 65.63 in the post-test, indicating students' improved ability to apply engineering principles to solve problems. Meanwhile, mathematics literacy increased from a pretest score of 36.46 to 57.29 in the post-test, illustrating students' improved skills in applying mathematical concepts practically. Overall, these improvements in scores illustrate the success of improving students' STEM literacy, which is essential for their 21st-century skill development.

The study results showed that implementing STEM-EDP can significantly improve students' STEM literacy. This can be seen from the difference in pretest and post-test results on the science literacy indicator, with an increase of 28.13 points and mathematics literacy of 20.83 points. This increase reflects the effectiveness of the STEM EDP approach in developing students' science and mathematics literacy abilities through the earthquake-resistant house disaster mitigation project. Projects relevant to real life, such as earthquake-resistant house disaster mitigation, help students understand how science and mathematics concepts are applied practically. This makes learning more meaningful so that students are more motivated to learn. The STEM EDP syntax with 8 stages, namely defining the problem, gathering information, planning, building, testing, evaluating, redesigning, and communicating, allows students to engage in an in-depth learning process, from identifying problems to evaluating and communicating results. Each stage allows students to develop conceptual understanding and problem-solving skills. The STEM EDP approach emphasizes the integration of science, technology, engineering, and mathematics, which

allows students to see the relationship between disciplines. This can improve their understanding of the concept as a whole.

Overall, the comparison between the control and experimental classes shows that STEM-EDP-based learning is more effective in improving student learning outcomes. The greater improvement in the experimental class indicates that this approach improves understanding of the material and provides greater opportunities for students to develop according to 21st-century needs, such as collaboration and problem-solving skills. These results reinforce the importance of implementing PjBL learning methods to significantly improve learning outcomes.

STEM literacy refers to an individual's ability to apply an understanding of how tight competition works in the real world that requires interrelated science, technology, engineering and mathematics (Ardianto et al., 2019). It is a dynamic process that involves analytical thinking, collaboration, participation, and the ability to understand and apply STEM concepts in addressing personal, social, and global challenges that cannot be solved by a single field of science (Jackson et al., 2021). At the K-12 education level, STEM literacy is crucial in fostering creativity, innovation, problem-solving, critical thinking, and effective communication skills (Jackson et al., 2021).

PjBL with the STEM-EDP approach has been proven effective in enhancing students' STEM literacy. This study found that the experimental class that implemented STEM-EDP-based learning significantly improved STEM literacy compared to the control class, which used conventional learning methods. These findings align with (Tari et al., 2023) research, which highlights the effectiveness of STEM-based modules as an alternative learning method to improve STEM literacy. Similarly, (Slough, 2013) supports the idea that project-based learning with a STEM approach enhances students' problem-solving and collaboration skills. Additionally, research by (Muslihah et al., 2024) suggests that the STEM-EDP learning model is worth considering to strengthen students' scientific understanding.

The implementation of STEM-EDP not only improves students' conceptual understanding but also develops practical skills applicable in real-life contexts. Project-based learning allows students to explore real-world problems and create innovative solutions, ultimately deepening their STEM literacy. Engaging students in hands-on projects, such as designing an earthquake-resistant house prototype, provides them with theoretical knowledge and practical experience applying STEM concepts. This approach helps students bridge the gap between theory and practice, enhancing their ability to solve complex problems.

The learning stages of STEM-EDP in the experimental class significantly impacted students' STEM literacy. These stages include defining the problem, gathering information, planning, building, testing, evaluating, redesigning, and communicating, all of which foster critical and analytical thinking. Each phase encourages students to identify issues, design solutions, test and refine their ideas and present their findings. In contrast, the control class followed conventional methods that did not incorporate these stages, limiting students' exposure to hands-on learning experiences crucial for improving STEM literacy.

The products developed through the STEM-EDP demonstrate students' ability to apply scientific concepts through hands-on experience and problem-solving. Through this process, students enhance their technical skills and develop critical thinking, collaboration, and innovation—key competencies for real-world challenges. The resulting projects, including prototype designs and physical models, reflect students' deep understanding of STEM concepts and their ability to create solutions relevant to daily life. Therefore, STEM-EDP effectively improves students' STEM literacy and prepares them for an increasingly technology-driven world (Jackson et al., 2021).

The product result of the STEM-EDP developed by students demonstrates the application of scientific concepts they learn through practical experiences and problem-

solving. In this project, students develop technical skills and critical thinking, collaboration, and innovation skills, which are very important in preparing them for real-world challenges. The resulting products reflect their deep understanding of the material, as well as the ability to design solutions that are relevant to the context of everyday life. Through this process, students are expected to not only master theoretical knowledge but also be able to apply it in the form of prototypes or models that can be measured and evaluated based on predetermined criteria. The results of student products in the form of prototype designs and prototype buildings can be seen in Figure 3.



**Figure 3.** Results of STEM PjBL products on earthquake-resistant house material

After participating in learning through the STEM-EDP approach, students showed a significant improvement in their understanding of designing earthquake-resistant house prototypes. This learning process encouraged students to integrate concepts from various disciplines, such as physics (force and motion), technology (building materials), and mathematics (structural calculations), allowing them to create structures capable of withstanding earthquake shocks. Additionally, through collaboration and hands-on experimentation, students gained insights into the importance of innovative design and construction technology to enhance building resilience. This experience increased their theoretical knowledge and honed their practical skills in constructing a prototype that meets earthquake safety standards.

The results of the earthquake-resistant house prototype developed by students demonstrate their successful application of acquired knowledge and skills (English et al., 2017). After conducting a shaking test, their prototype passed the shock resistance test,

proving that their design and materials were effective in withstanding earthquake-induced loads. This success reflects their deep understanding of earthquake-resistant structures and ability to apply theoretical knowledge in practice. Moreover, these findings indicate academic progress and highlight their preparedness to tackle real-world challenges with science and technology-based solutions.

In this project, students were tasked with designing, constructing, and testing a prototype house that could withstand earthquakes, integrating concepts from multiple disciplines. To ensure structural stability, they needed to understand forces and motion (physics), earthquake-resistant materials (engineering), and mathematical calculations. This interdisciplinary approach enabled them to see how different concepts interact in real-world applications (Stehle & Peters-Burton, 2019). As a result, their STEM literacy improved, as they learned theoretical principles and how to apply them in practical problem-solving scenarios.

Beyond STEM literacy, the implementation of STEM-EDP positively impacted students' problem-solving skills (Abdurrahman et al., 2023). Working in groups, students were required to communicate effectively, share ideas, and negotiate solutions to achieve a common goal. Each member played a unique role, making collaboration essential to success. This process taught students to leverage individual strengths, resolve conflicts, and work efficiently as a team (Marra et al., 2016). Thus, STEM-EDP fostered technical competencies and crucial social skills that are vital for their future careers.

The importance of collaboration became evident in creating the earthquake-resistant house prototype. To design and test a stable structure, students had to divide responsibilities, including designing blueprints, selecting materials, and conducting resistance tests. This teamwork allowed them to utilize various skills, from design and data analysis to material testing. The prototype evaluation also required group discussions and assessments to determine whether their designs met the expected standards. Their success in passing the shaking test underscores the role of collaboration in achieving common objectives (Amelia & Santoso, 2021; Stehle & Peters-Burton, 2019).

Another key outcome of STEM-EDP implementation was enhancing students' integrative and application skills. Instead of merely understanding theoretical concepts, students were trained to merge knowledge from various disciplines to create practical solutions. In this project, they combined expertise in structural design, earthquake-resistant materials, and construction techniques to produce a tangible and testable model. The successful shaking test proved their ability to apply their learning innovatively and effectively. This confirms that the STEM-EDP approach strengthens students' technical skills and prepares them to face real-world challenges with confidence and competence.

## **Conclusion**

This study effectively answers the research objectives and problem formulation by demonstrating that the STEM-EDP approach significantly improves students' STEM literacy and learning outcomes through measurable academic gains and enhanced soft skills. The experimental class, which implemented the STEM-EDP-based learning model, showed a moderate improvement in learning outcomes with an N-gain value of 0.331, compared to the control class's lower N-gain of 0.23. Furthermore, the post-test scores of the experimental class reached a maximum of 80, while the control class only achieved a score of 70. Statistical analysis using the Wilcoxon test confirmed that these improvements were significant and resulted from the PjBL intervention. The integration of real-world projects such as designing earthquake-resistant house prototypes enabled students to apply concepts from physics, engineering, and mathematics in solving complex problems, thereby enhancing both their academic understanding and key 21st-century skills such as collaboration, communication, and problem-solving. These findings validate that the STEM-

EDP approach is not only effective in boosting academic achievement but also in equipping students with the interdisciplinary and social competencies essential for future professional success.

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