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The Effect of Entrepreneurial-STEM (E-STEM) Learning on High School Students' Problem-Solving Skills

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ABSTRACT
This study aimed to determine the effect of the Entrepreneurial-STEM (E-STEM) learning model on students' problem-solving skills in the topic of environmental change in Grade 10 biology. The E-STEM model integrates science, technology, engineering, and mathematics with entrepreneurial practices through contextual project-based learning. A quasi-experimental design using a Non-Equivalent Control Group was employed in two classes at a public senior high school in Sukabumi City, involving 31 students in the experimental group and 29 students in the control group. Research instruments included an essay test based on Polya's problem-solving indicators, a student response questionnaire, and a learning implementation observation sheet. Data analysis involved normality and homogeneity tests, hypothesis testing (Mann-Whitney), normalized gain (N-Gain), and triangulation of quantitative and qualitative data. The results indicated a significant difference in posttest scores between the experimental and control groups, with the experimental group achieving a higher N-Gain (0.55, medium category) compared to the control group (0.24, low category). The most notable improvements occurred in the planning and evaluating solution indicators. Learning implementation reached 91.70% and student responses averaged 80.32%, both classified as very good. These findings suggest that the E-STEM model has a positive and significant effect on enhancing students' structured and meaningful problem-solving skills. This study provides contextual empirical evidence for Indonesian biology education and highlights the need for further research with broader samples and longer implementation periods to strengthen the generalizability of the findings.

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1. INTRODUCTION

The 21st century requires education not only to transmit knowledge but also to serve as a catalyst for developing higher-order thinking skills, enabling students to adapt and respond to change in innovative ways (Hubers, 2022; Muhibbudin et al., 2023). One of the most essential skills in this context is problem-solving, which is recognized as a fundamental component of 21st-century competencies along with critical thinking, communication, collaboration, and creativity (Mehadi Rahman, 2019; Selviani et al., 2025). Problem-solving is generally defined as a systematic process that involves identifying problems, designing and implementing solutions, and evaluating outcomes (English & Sriraman, 2009). In science learning, these skills are crucial as they train students to think logically, reflectively, and to connect scientific knowledge with real-world challenges (Elvianasti et al., 2022; Wahyuni et al., 2018). Therefore, nurturing problem-solving skills must become a central focus of biology education.

Numerous empirical studies have reported the low levels of students' problem-solving abilities across educational levels in Indonesia. Medyasari et al. (2020) found that high school students' mathematical problem-solving performance remains low, with the highest achievement at the stage of understanding problems (66%) and the lowest at the stage of checking solutions (48%), resulting in an overall average of only 53.4%. Similarly, Rosdiana et al. (2024) reported that students' problem-solving ability in the topic of global warming was mostly in the low to very low categories, with an average score of only 26.1 out of 100—12 out of 30 students were in the "very low" category. Haryati & Warmi (2021) also revealed that junior high school students' problem-solving skills were low, with only 25% reaching the level of understanding the problem and an overall average of 21%. Likewise, Romaito et al. (2024) observed that the highest indicator achieved was 63.87% for understanding the problem, while only 27.76% reached the checking stage, placing students' overall performance in the low category. A preliminary observation at a senior high school in Sukabumi City confirmed this condition, where diagnostic tests and classroom observations revealed students' difficulties in understanding problems, developing strategies, and evaluating solutions independently.

This underachievement is presumed to be linked to the continued use of conventional learning approaches. Classroom instruction tends to be dominated by lecture-based and one-way teaching methods, offering little space for students to apply biology concepts in meaningful contexts. Interviews with teachers indicated that exploration, deep discussion, and project-based experimentation were rarely implemented. These findings align with Sibarani & Mendrofa (2024), who reported that students learning through lectures showed significantly lower problem-solving performance than those taught using Problem-Based Learning (PBL). Maulidah et al. (2023) also emphasized that teacher-centered instruction limits students' opportunities to think critically and reflectively, hindering the development of systematic problem-solving capabilities. These studies show that the lack of problem-solving skills is not only due to internal student factors, but is also strongly influenced by instructional approaches that fail to foster contextual high-level thinking. One promising approach to address this issue is the Entrepreneurial-STEM (E-STEM) model, which integrates project-based learning with entrepreneurial values and real-world contexts to comprehensively and meaningfully enhance problem-solving abilities Eltanahy & Mansour (2022).

E-STEM is an expansion of the STEM approach, which integrates science, technology, engineering, and mathematics, by incorporating entrepreneurship to overcome limitations of the conventional STEM model. Although STEM has been widely used to cultivate logical thinking and problem-solving through interdisciplinary integration, its classroom application often focuses on technical solutions and lacks attention to social relevance or utility (Rosiningtias et al., 2023). E-STEM broadens the scope of problem-solving by encouraging students not only to design scientific solutions but also to recognize opportunities, assess utility, and consider the social sustainability of their proposed ideas (Eltanahy et al., 2020; Kaya-capocci & Peters-burton, 2023). As a result, E-STEM fosters problem-solving that is more contextual, reflective, and applicable. Previous studies also report that this model enhances students' ability to plan strategies, make decisions, and evaluate solutions meaningfully and systematically (Kaya-Capocci et al., 2024).

Although the Entrepreneurial-STEM (E-STEM) learning model has been widely explored at the global level, its implementation in Indonesian biology classrooms remains undocumented in academic literature. Most existing studies in the local context still focus on conventional STEM approaches and have yet to incorporate entrepreneurial elements. However, contextual problem-solving is particularly relevant in biology education, especially in topics such as environmental change. Moreover, most previous studies have concentrated on general cognitive outcomes without analyzing the improvement of specific indicators within the problem-solving process. Studies that integrate E-STEM with triangulated data sources such as implementation observations and student responses are also rarely reported. Therefore, this study seeks to fill these gaps by providing contextual empirical evidence on the effectiveness of the E-STEM learning model in enhancing students' problem-solving skills, specifically in the indicators of understanding the problem, planning a solution, carrying out the solution, and evaluating the solution in a senior high school biology setting.

2. RESEARCH METHOD

This study employed a quantitative approach using a quasi-experimental method. The design used was a Non-Equivalent Control Group Design, involving two student groups an experimental group and a control group that were not randomly selected but considered to have equivalent initial characteristics. This design aimed to examine the effect of E-STEM learning on students' problem-solving skills in the topic of environmental change. The experimental group received learning based on the E-STEM model, while the control group received instruction using the Discovery Learning model. The experimental design is presented in Table 1.

Table 1 Non-Equivalent Control Group Design

Group	Pretest	Treatment	Posttest
Experimental	O_1	X_1	O_2
Control	O_1	X_2	O_2

(Sugiyono, 2013)
Keterangan :
Note:
O1 = Pretest of problem-solving

O2 = Posttest of problem-solving
X1 = E-STEM learning treatment
X2 = Discovery Learning treatment.

The participants of this study were tenth-grade students at State Senior High School 1 Sukabumi City in the 2024/2025 academic year. Two classes were selected as samples: Class X.6 (31 students) served as the experimental group, and Class X.10 (29 students) as the control group.

The research was carried out in four stages, namely: (1) the preparation stage, which included coordination with the school, instrument validation, and the assignment of experimental and control classes; (2) the pretest stage, conducted to measure the initial problem-solving skills; (3) the treatment stage, in which the experimental class received E-STEM learning, while the control class received Discovery Learning; and (4) the evaluation stage, which was carried out through posttests and the completion of student response questionnaires after all learning activities were completed.

The instruments included eight essay items developed based on Polya's (1973) problem-solving stages, which consist of understanding the problem, planning a solution, carrying out the solution, and evaluating the solution, to assess students' problem-solving abilities. These instruments underwent a validation process consisting of content validity, reliability testing, and limited trials. Content validity was carried out by one biology education lecturer as an expert validator, who assessed the essay items, student response questionnaire, and observation sheet in terms of relevance, clarity, and alignment with the indicators. The validation results indicated that all instruments were in the "very feasible" category, with an average score above 3.25 on a 4-point scale. The reliability of the essay test was analyzed using Cronbach's Alpha, yielding a coefficient of 0.77, which falls into the high category (Arikunto, 2019). A limited trial was also conducted on 20 students outside the research sample to test item clarity, difficulty level, and discrimination power. Based on the analysis, the test items demonstrated acceptable difficulty levels and significant item-total correlations, ensuring the quality and appropriateness of the instrument for the main study. In addition, the validated Likert-scale questionnaire was used to gauge students' responses toward the E-STEM learning experience, along with a validated observation sheet to monitor the implementation of learning activities.

Data collection in this study was conducted during May 2025 at State Senior High School 1 Sukabumi City. The data collected included students' problem-solving skills before and after the learning process, learning implementation, and student responses toward the E-STEM model. The details of the instruments, types of data, time of implementation, and data sources are presented in

Table *2* below.

Table 2 Data Collection Techniques

No	Instrument	Type of Data	Time	Source
1	Problem-solving test items	Analysis of students' problem-solving skills before and after E-STEM learning	Before and after learning	Students
2	Learning implementation observation sheet	Data on the implementation of E-STEM-based project-based learning in class	During the learning process	Students
3	Student response questionnaire	Results of students' responses toward E-STEM learning and E-STEM projects	After learning	Students

Data analysis in this study was carried out quantitatively using SPSS version 22 software. The data from the measurement of problem-solving skills were analyzed using descriptive statistics to obtain the mean and standard deviation of pretest and posttest scores. The normalized gain (N-Gain) was calculated to determine the improvement in student scores. The N-Gain values were then classified into specific categories referring to Hake's (1998) criteria, as presented in **Error! Reference source not found.**.

Table 3 N-Gain Categories

N-Gain Range	Category
≥ 0.7	High
$0.3 \leq$ N-Gain < 0.7	Medium
< 0.3	Low

The data from the student response questionnaire toward E-STEM learning were analyzed quantitatively using descriptive percentages. The final score was calculated from the total of all statement items, then classified based on the score interpretation criteria according to Sugiyono (2018), as shown in **Error! Reference source not found.**.

Table 4 Student Response Percentage Categories

Percentage Score	Category
81% – 100%	Very Good
61% – 80%	Good
41% – 60%	Fair
≤ 40%	Poor

Meanwhile, the data from the learning implementation observation sheets, which consisted of 4 indicators, were analyzed by calculating the total percentage of implementation. The observations were conducted collaboratively by one biology teacher and two researchers to ensure objectivity and reliability of the observation process. These percentages were then categorized based on Sugiyono (2022) criteria as presented in **Error! Reference source not found.**.

Table 5 Learning Implementation Percentage Categories

Percentage Score	Category
≥ 80%	Very Good
66% – 79%	Good
56% – 65%	Fair
≤ 55%	Poor

3. RESULT AND DISCUSSION

This study aimed to investigate the effect of the Entrepreneurial-STEM (E-STEM) learning model on students' problem-solving skills in the topic of environmental change. Data were collected through pretest and posttest using essay items based on Polya's problem-solving stages, accompanied by a student response questionnaire and an observation sheet on learning implementation.

Table 6 Average Pretest and Posttest Scores in Problem-Solving

Data	Class	Average Score	
		Pretest	*Postest*
Problem-Solving	Experimental	34,58±1,56	70,56±1,39
	Control	35,13±1,72	50,97±1,39

Error! Reference source not found. shows that there was a higher increase in the average score in the experimental class compared to the control class after the learning process. To ensure the validity of the hypothesis testing results, assumption testing was conducted through normality and homogeneity tests. The normality test was performed using the Shapiro-Wilk test. The results are presented in **Error! Reference source not found.**.

Table 7 Shapiro-Wilk Normality Test for Experimental and Control Classes

Stage	Class	Sig. (Shapiro-Wilk)	Interpretation
Pretest	Control	0.407	Normal
Pretest	Experimental	0.118	Normal
Posttest	Control	0.095	Normal
Posttest	Experimental	0.001	Not Normal

The results show that the posttest data of the experimental class were not normally distributed, while the other data were normally distributed. The next step was to test for homogeneity to ensure the equality of variances between groups. The homogeneity test was conducted using Levene's Test, as shown in **Error! Reference source not found.**.

Table 8 Homogeneity Test Results

Stage	Sig. (Levene)	Interpretation
Pretest	0.713	Homogeneous (Sig. > 0.05)
Posttest	0.995	Homogeneous (Sig. > 0.05)

From the results, it can be concluded that both the pretest and posttest data had homogeneous variances across the groups. However, since one dataset was not normally distributed, the hypothesis test was carried out using the non-parametric Mann-Whitney U test, the results of which are shown in

Table 9.

Table 9 Hypothesis Test Results

Test	Posttest
Mann-Whitney U	26.500
Wilcoxon W	461.500
Z	-6.294
Asymp. Sig. (2-tailed)	0.000

The test results on posttest data show an Asymp. Sig. value of 0.000 ($p < 0.05$), indicating a very significant difference between the posttest results of the experimental and control classes. After confirming that the E-STEM learning implementation had a significant effect, the next step was to analyze the extent of improvement in problem-solving skills between the experimental and control classes. This improvement was measured using the Normalized Gain (N-Gain), both overall and based on each indicator of problem-solving skills according to Polya's stages. Table 10 shows that the experimental class experienced higher and more effective improvement compared to the control class. The experimental class obtained an N-Gain score of 0.55, which is categorized as medium, while the control class obtained 0.24, which is categorized as low. Thus, the N-Gain difference of 0.31 not only reflects a numerical gap but also demonstrates a substantial quality difference in improvement between the two classes.

Table 10 N-Gain Scores Between Classes

Class	N-Gain (± SD)	N-Gain Category
Experimental	0.55 ± 0.02	Medium
Control	0.24 ± 0.02	Low

The results of this study indicate that the E-STEM learning model had a significant impact on improving students' problem-solving skills. This is evidenced by the hypothesis test results presented in

Table 9, which show a posttest score difference between the experimental and control groups after the intervention. Additionally, the comparison of N-Gain values indicates a greater increase in the problem-solving skills of students in the experimental group compared to the control group. These findings suggest that the E-STEM model effectively supports students' cognitive development across the stages of understanding the problem, planning a solution, carrying out the solution, and evaluating the result. Thus, E-STEM is not only statistically effective but also contributes positively to reinforcing students' structured and applicable problem-solving abilities.

This finding is supported by Kaya-Capocci et al. (2024), who developed the Entrepreneurial-STEM model to enhance student independence and problem-solving capabilities through context-based projects. Their study revealed that students engaged in E-STEM showed significant improvement in reflective and creative thinking due to their active involvement in designing solutions and evaluating their environmental impact. Similarly, research by Eltanahy & Mansour (2022) in the United Arab Emirates demonstrated that integrating entrepreneurial practices into STEM learning helped students connect scientific concepts to real-world challenges. Their version of the E-STEM model was proven to enhance students' systematic thinking and applicable problem-solving skills. Both studies reinforce the present findings, highlighting that E-STEM not only improves learning outcomes quantitatively but also cultivates higher-order thinking skills essential for addressing contextual problems.

In addition to the overall analysis, problem-solving skill improvement was also examined based on the four indicators proposed by Polya (1973). The results are presented in Figure 1.

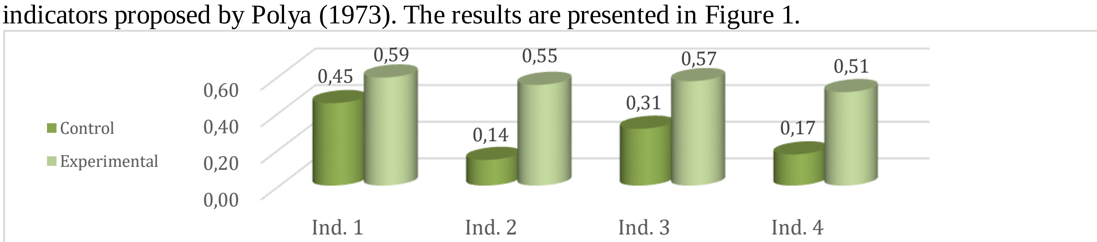

Figure 1 N-Gain per Indicator for Problem-Solving Skills in Experimental and Control Classes

The improvement in students' problem-solving skills across each indicator also revealed a significant difference between the experimental and control groups. As shown in Figure 1, the most notable N-Gain differences were observed in the indicators of *planning solutions* and *evaluating solutions*, with respective differences of 0.41 and 0.34. These findings indicate that E-STEM learning exerts a strong influence in fostering students' strategic thinking and their ability to critically assess the effectiveness of their proposed solutions. Throughout the learning process, stages such as brainstorming and SWOT analysis provided students with opportunities to examine multiple solution alternatives analytically, while the business planning stage encouraged them to re-evaluate the feasibility of their ideas in terms of sustainability and real-world utility. This demonstrates that E-STEM is not limited to product development, but rather promotes structured, complex, and reflective thinking processes.

The effectiveness of E-STEM in developing these higher-order thinking skills can be attributed to the distinctive nature of its approach, which positions students as solution designers operating within authentic contexts. Instead of solving routine textbook exercises, students are actively engaged in formulating strategic responses to real-world environmental issues. In doing so, they are not only practicing low-level cognitive processes but are also engaging in judgment, ethical reflection, and long-term sustainability planning. This aligns with the view of Kaya-Capocci et al. (2024), who stated that the success of E-STEM lies in how each stage fosters a recurring cycle of critical and reflective thinking, rather than focusing solely on the creation of a final product. Eltanahy & Mansour (2022) also emphasized that reflective problem-solving skills can only be effectively cultivated when students are given sustained opportunities to make decisions and evaluate their solutions in an explicit and iterative manner.

The effectiveness of E-STEM learning in enhancing students' problem-solving skills is further supported by qualitative data derived from student responses and learning implementation observations. Based on the questionnaire results, the average score reached 80.32%, indicating that students rated the learning process as highly effective. The highest ratings were observed in aspects such as clarity of instruction, student engagement, ease of understanding, and real-life relevance. Several students also emphasized these points in their open-ended responses. For instance, one student stated, *"Learning with the E-STEM model trained my ability to solve problems logically."* These findings suggest that the E-STEM model successfully fostered an active, meaningful, and student-centered learning environment. A graphical representation of student response distribution is presented in Error! Reference source not found..

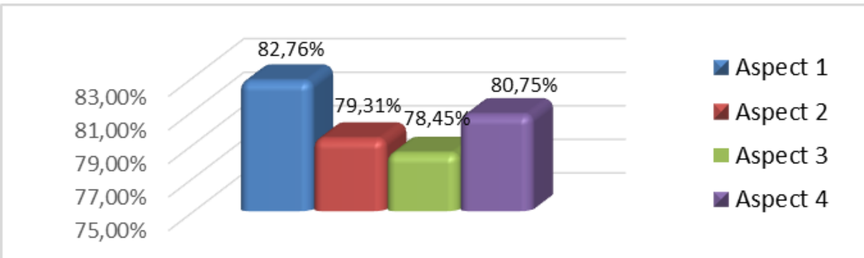

Figure 2 Percentage of Student Response Questionnaire Results toward the E-STEM Model

Such positive responses are closely associated with the structured implementation of the E-STEM syntax carried out in this study. The learning model was implemented through a series of stages: ability determination, brainstorming, SWOT analysis, prototype development, interdisciplinary project design, and value-added planning. Each stage was intentionally designed to cultivate students' systematic and applicable problem-solving abilities. For instance, the brainstorming and SWOT analysis stages provided opportunities for students to critically evaluate a range of solution alternatives, while the prototyping and business planning stages encouraged them to formulate realistic, measurable, and sustainable solutions.

In addition to the questionnaire data, observational evidence of the learning implementation supports these results. The overall implementation rate reached 91.70%, indicating that the E-STEM syntax was carried out with a high degree of fidelity and effectiveness. This level of completion is categorized as excellent and demonstrates that each stage of the learning process was executed as intended. Detailed results of the implementation effectiveness across stages are illustrated in Error! Reference source not found..

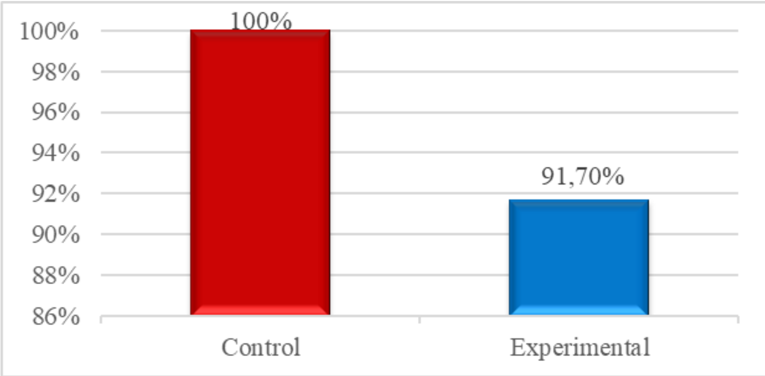

Figure 3 Percentage of Learning Implementation in the Experimental and Control Classes

These findings align with previous research by Eltanahy & Mansour (2022), who emphasized that the stages of the E-STEM model are explicitly designed to train students in problem identification, strategic solution design, and reflective evaluation of outcomes. Similarly, Kaya-Capocci et al. (2024) asserted that the project-based and exploratory nature of the E-STEM syntax plays a pivotal role in developing students' systematic thinking skills, especially in addressing complex, real-world problems. Therefore, the high level of student satisfaction and the successful implementation of all learning stages in this study serve as clear indicators of E-STEM's substantial contribution to the gradual and meaningful development of students' problem-solving competencies. However, this study has certain limitations, such as being conducted only in one school with a relatively short research duration, which may restrict the generalizability of the findings. These limitations highlight the need for further studies with broader samples and longer implementation periods to strengthen the evidence of E-STEM's effectiveness.

4. CONCLUSION

This study concludes that the Entrepreneurial-STEM (E-STEM) learning model significantly improves students' problem-solving skills in the context of environmental change. The most substantial improvements were observed in the indicators of planning and evaluating solutions, indicating that the E-STEM learning model effectively fosters students' ability to formulate, carry out, and reflect on problem-solving strategies in a systematic manner. These findings are supported by triangulation data, including highly positive student responses and high instructional implementation levels, reflecting the successful application of the E-STEM syntax in facilitating an active, contextual, and meaningful learning process. Therefore, the E-STEM learning model can be recommended as an effective alternative for enhancing students' stepwise and applicable problem-solving skills in secondary school biology education.

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