Integration of STEM Biology in Physics Learning Oriented Toward 21st-Century Skills

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ABSTRACT
This study aimed to analyze the effect of STEM–Biology integrated physics learning on junior high school students' 21st-century skills, including critical thinking, creativity, collaboration, and communication. The study employed a quantitative approach using a quasi-experimental design with a nonequivalent control group design. The research was conducted at SMPN 2 Peusangan during the even semester of the 2024/2025 academic year, involving two eighth-grade classes as the experimental and control groups selected through purposive sampling. The experimental group received STEM–Biology integrated physics learning, while the control group received conventional instruction. Data were collected using written tests, 21st-century skills questionnaires, and observation sheets, and were analyzed using t-tests and N-Gain analysis. The results showed that the N-Gain score of the experimental group was in the moderate–high category (0.63), which was higher than that of the control group (0.34). Therefore, STEM–Biology integrated physics learning is effective in developing junior high school students' 21st-century skills.

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1. Introduction

The rapid development of science and technology in the 21st century has significantly influenced the competency demands placed on students. Science education is no longer sufficient if it focuses solely on conceptual mastery; instead, it must emphasize the development of higher-order thinking skills, including critical thinking, creativity, collaboration, and communication (4C), which are recognized as essential 21st-century competencies (Rahmaniar & Latief, 2021). However, science learning in schools is still predominantly characterized by conventional approaches that emphasize rote memorization, resulting in limited facilitation of 21st-century skills development.

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The STEM (Science, Technology, Engineering, and Mathematics) approach is considered a relevant instructional strategy to address these challenges. STEM-based learning emphasizes interdisciplinary integration, contextual problem-solving, and the application of scientific concepts to real-world situations. Systematic reviews have shown that STEM approaches can enhance students' critical thinking skills, creativity, and collaborative abilities in science learning (Fitria et al., 2023). Nevertheless, the implementation of STEM in schools is often partial and has not been fully integrated across science content areas.

At the junior high school level, science is taught as an integrated subject that encompasses physics, biology, and chemistry concepts within a unified curriculum. This condition provides substantial opportunities to develop integrative and contextual science learning. The integration of physics and biology is particularly relevant, as many biological phenomena can be explained through physical principles, such as mechanics in the human locomotion system, pressure concepts in the circulatory system, and energy transformation in metabolic processes. Integrating physics and biology through a STEM approach has the potential to foster more holistic conceptual understanding while simultaneously developing students' 21st-century skills (Hazana, 2024).

Previous studies indicate that the implementation of STEM in science learning is commonly combined with specific instructional models, such as Project-Based Learning or Problem-Based Learning, with a primary focus on improving cognitive learning outcomes or individual skill aspects. Studies that specifically examine STEM–Biology integration in physics learning at the junior high school level, particularly those oriented toward the comprehensive development of 21st-century skills, remain relatively limited. Furthermore, biological contexts in STEM-based physics learning are often not utilized systematically as the primary foundation for designing learning activities (Megawati et al., 2023). This study differs from previous research in that it does not merely integrate STEM thematically but positions biological contexts as the primary basis for designing physics learning activities. Consequently, the learning process is designed to be more contextual and holistic, strengthening interdisciplinary conceptual understanding while comprehensively fostering 21st-century skills.

Based on these considerations, empirical research is needed to examine the implementation of STEM–Biology integrated physics learning as an alternative instructional approach capable of addressing the demands of 21st-century skills development. Therefore, this study aims to analyze the effect of STEM–Biology integrated physics learning on the 21st-century skills of eighth-grade junior high school students, including critical thinking, creativity, collaboration, and communication. The findings of this study are expected to contribute theoretically to the development of integrated STEM learning research and practically to support science teachers in designing integrative, contextual, and 21st-century-oriented learning experiences.

2. Research Method

This study employed a quantitative approach using a quasi-experimental design with a nonequivalent control group design. The research was conducted at SMPN 2 Peusangan during the even semester of the 2024/2025 academic year over eight meetings, including pretest and posttest sessions. The research population comprised all eighth-grade students of SMPN 2 Peusangan. The sample consisted of two classes selected through purposive sampling by considering the equivalence of students' initial abilities, with one class assigned as the experimental group and the other as the control group. Each class consisted of approximately 30–32 students.

The independent variable in this study was STEM–Biology integrated physics learning, while the dependent variable was students' 21st-century skills, including critical thinking, creativity, collaboration, and communication. The research procedure was conducted in three main stages: preparation, implementation, and final stage. During the preparation stage, learning devices and research instruments were developed and validated. The implementation stage began with administering a pretest to both the experimental and control groups, followed by the application of STEM–Biology integrated physics learning in the experimental group and conventional learning in the control group. The final stage involved administering a posttest and collecting supporting data.

Data were collected using written tests to measure students' critical thinking skills, questionnaires to assess creativity, collaboration, and communication skills, and observation sheets to examine the implementation of the learning process. Instrument validity was examined through content validity involving science education experts and educational evaluation experts, while the reliability of the 21st-century skills questionnaire was analyzed using Cronbach's Alpha coefficient. The questionnaire employed a five-point Likert scale, categorized as follows: (1) strongly disagree, (2) disagree, (3) neutral, (4) agree, and (5) strongly agree. Instruments that were confirmed to be valid and reliable were subsequently used for data collection.

3. Results and Discussion

Results

The results of the study indicate that STEM–Biology integrated physics learning had a positive effect on improving students' 21st-century skills. A comparison of pretest and posttest results between the experimental and control groups revealed a considerable difference in learning gains. Overall, the experimental group achieved higher average posttest scores and N-Gain values than the control group across all aspects of 21st-century skills.

Table 1. Mean Scores of Pretest, Posttest, and N-Gain of 21st-Century Skills

Group	Pretest	Posttest	N-Gain	Category
Experimental	54.2	82.6	0.63	Moderate–High

Control	55.1	70.4	0.34	Low–Moderate

Note: The N-Gain categories were determined based on Hake's criteria.

Based on Table I, both groups exhibited relatively equivalent initial abilities. However, after the instructional treatment, the experimental group showed a greater improvement than the control group. The t-test analysis of N-Gain scores indicated that the difference in the improvement of 21st-century skills between the two groups was statistically significant, leading to the conclusion that STEM–Biology integrated physics learning was more effective than conventional learning.

When examined across each aspect of 21st-century skills, the results revealed variations in the level of improvement, as presented in Table II.

Table 2. Average N-Gain Scores for Each Aspect of 21st-Century Skills

Skill Aspect	**Experimental Group**	**Category**	**Control Group**	**Category**
Critical Thinking	0.68	High	0.36	Medium
Creativity	0.60	Medium	0.33	Low-Medium
Collaboration	0.66	Medium-High	0.35	Medium
Communication	0.58	Medium	0.32	Low-Medium

Source: Research findings (2025)

Table 2 shows that critical thinking and collaboration skills experienced the highest improvement in the experimental group, while creativity and communication skills also demonstrated greater improvement compared to the control group. To further clarify the comparison of 21st-century skills improvement between the two groups, the N-Gain data are presented in the form of a bar chart, as shown in Figure 1.

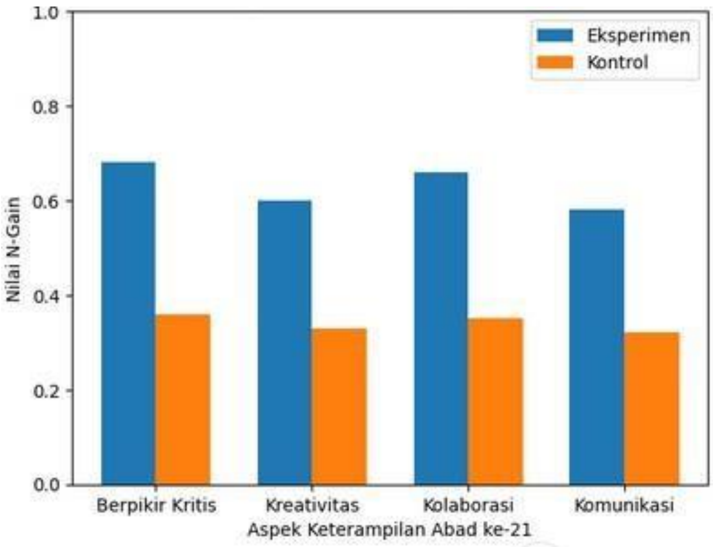

Figure 1. Comparison of N-Gain in 21st-Century Skills

Discussion

The results of this study indicate that STEM–Biology integrated physics science learning is effective in enhancing junior high school students' 21st-century skills. These findings can be explained by the characteristics of STEM-based learning, which emphasize contextual problem-solving, interdisciplinary integration, and active student engagement in the learning process. Integrating biological contexts into physics learning enables students to relate abstract concepts to real-life phenomena, making learning more meaningful and relevant to their learning experiences.

The higher improvement in critical thinking skills observed in the experimental group suggests that learning activities requiring students to analyze problems based on biological phenomena using physics approaches effectively train their analytical, evaluative, and decision-making abilities. This finding is consistent with the view that STEM learning encourages students to engage in higher-order thinking processes through authentic, context-based problem-solving (Bybee, 2022).

Furthermore, the improvement in collaboration and communication skills in the experimental group indicates that STEM–Biology integrated physics learning provides greater opportunities for students to work collaboratively, engage in discussions, and express ideas. Group work activities and result presentations promote constructive social interaction, thereby fostering the development of communication and collaboration skills. This finding aligns with the study by Rahmawati and Nugraha (2023), which reported that STEM integration in junior high school science learning contributes positively to the development of 21st-century skills, particularly collaboration and communication.

Meanwhile, the improvement in students' creativity skills in the experimental group was categorized as moderate, yet it remained higher than that of the control group. This finding indicates that STEM–Biology integrated physics learning encourages students to generate ideas, design solutions, and explore various alternatives for problem-solving based on biological contexts and physics principles. Learning activities involving simple product design, open discussions, and group-based decision-making provide opportunities for students to express ideas flexibly and originally. However, the level of creativity achieved has not yet reached a high category, suggesting that students are still adapting to open-ended and exploratory learning environments. This condition is influenced by prior learning experiences that tended to emphasize single correct answers and procedural approaches. Therefore, the continuous and consistent implementation of STEM–Biology integrated physics learning has the potential to further strengthen students' creativity skills, along with the development of divergent thinking habits and increased confidence in expressing ideas. This finding is consistent with previous studies indicating that STEM learning promotes creativity through design-based activities and open-ended problem-solving (Megawati et al., 2023).

4. Conlusion

This study demonstrates that STEM–Biology integrated physics science learning is effective in developing junior high school students' 21st-century skills, particularly critical thinking, creativity, collaboration, and communication. The integration of the STEM approach with biological contexts in physics learning is able to create more meaningful, contextual, and problem-oriented learning experiences, thereby supporting students' active engagement in the learning process. These findings confirm that the research objective, namely to examine the effect of STEM–Biology integrated physics science learning on students' 21st-century skills, has been successfully achieved.

The implications of this study indicate that STEM–Biology integrated learning can be adopted as an alternative instructional strategy for science education at the junior high school level to support the implementation of the Merdeka Curriculum and the strengthening of 21st-century competencies. In addition, the results provide a foundation for the development of more integrative and interdisciplinary science learning materials. Future research is recommended to examine the application of STEM–Biology integration in other science topics, involve larger and more diverse samples, and combine this approach with other innovative learning models to further enhance the sustainable development of 21st-century skills.

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