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THE EFFECT OF STEM-BASED PHYSICS LEARNING ON STUDENT CREATIVITY AND PROBLEM SOLVING

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ABSTRACT

STEM (Science, Technology, Engineering, and Mathematics)-based learning constitutes a critical aspect of physics education as it enables the holistic integration of multiple disciplines to foster 21st-century competencies. However, the low levels of students' creativity and problem-solving skills in physics learning remain fundamental issues that require immediate attention. This challenge underscores the need for further investigation into the effectiveness of STEM-based learning in enhancing students' creativity and problem-solving abilities. This study aims to analyze the effect of STEM-based physics learning on the creativity and problem-solving skills of senior high school students. The research employed a quasi-experimental method with a pretest–posttest control group design. Data were collected using a creativity assessment rubric and problem-solving ability tests validated by two expert lecturers. The collected data were analyzed using the Independent t-test and N-Gain test. The findings reveal a significant difference between the experimental and control groups in terms of creativity (sig. = 0.001; t = 5.41) and problem-solving skills (sig. = 0.002; t = 4.87). The N-Gain scores in the experimental group reached 0.54 for creativity and 0.49 for problem-solving skills, both categorized as moderate, whereas the control group only achieved low categories. These results indicate that STEM-based learning is effective in enhancing students' competencies. This study provides a significant contribution to the advancement of physics education at both national and international levels through the reinforcement of innovative STEM-based instructional models. Furthermore, the findings are expected to serve as a reference for future research, particularly in the development of instructional strategies aimed at improving creativity and problem-solving skills, as well as to encourage more in-depth and applicable follow-up studies.

Keywords: STEM-Based Learning, Creativity, Problem Solving, Physics Education, 21st Century Competencies.

INTRODUCTION

21st century education requires learners to possess competencies that extend beyond the mere mastery of academic content, encompassing higher-order thinking skills such as creativity, critical thinking, collaboration, and independent problem-solving (Sidiq et al., 2025). These competencies have become key indicators of educational quality at the global level (OECD, 2023). In this context, science education—particularly physics—plays a strategic role due to its inherent emphasis on analytical, exploratory, and innovative thinking. However, classroom practices in physics education are still predominantly characterized by teacher-centered approaches, where teachers serve as the primary source of knowledge and students act as passive recipients.

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This condition has contributed to the low levels of students' creativity and problem-solving abilities in physics learning. Several studies indicate that students tend to memorize formulas without being able to apply them across diverse problem contexts (Zulkarnain, 2021). Furthermore, when confronted with non-routine problems requiring creativity and higher-order reasoning, most students experience considerable difficulties. Johril (2022) reported that the dominance of lecture-based instruction and conventional exercises has hindered the development of higher-order thinking skills (HOTS) among secondary school students. This issue becomes increasingly critical in light of future workforce demands, which require individuals who are not only creative but also capable of solving complex problems (Studi et al., 2017).

In response to these challenges, there is a pressing need for more innovative, contextual, and meaningful learning approaches. One approach that has gained significant attention over the past decade is STEM-based learning (Science, Technology, Engineering, and Mathematics). STEM is not merely an integration of four disciplines; rather, it represents a learning paradigm that emphasizes the integrated solution of real-world problems. Through this approach, students are not only expected to understand physics concepts theoretically but are also actively engaged in designing solutions, testing hypotheses, utilizing technology, and applying mathematical principles in everyday contexts (Rahman et al., 2023).

From a theoretical perspective, STEM-based learning aligns with the constructivist theory proposed by Jean Piaget, which posits that knowledge is actively constructed by learners through direct experience and reflective processes (Nathasya, 2024). Moreover, this approach incorporates the principles of problem-based learning, which have been widely recognized as effective in fostering higher-order thinking skills, including creativity and problem-solving abilities. Therefore, the implementation of STEM in physics education is supported by a strong theoretical foundation and is highly relevant to the needs of contemporary education.

Previous studies have reported the positive impact of STEM implementation on various student learning outcomes. Zulkarnain (2021) demonstrated that integrating STEM into physics instruction significantly enhances students' conceptual understanding (Santosa et al., 2021). Other studies have also reported improvements in critical thinking skills through STEM-based projects, as well as increased student engagement and learning motivation (Sekarutami, 2020). However, most of these studies have focused on single dependent variables in isolation. Research that simultaneously examines the effects of STEM on both creativity and problem-solving skills within a unified framework remains limited. This gap constitutes a primary rationale for the present study (Kita et al., 2024).

The novelty of this study lies in its simultaneous investigation of two key competencies—creativity and problem-solving skills—within the context of STEM-based physics learning (Rifka Alkhilyatul Ma'rifat, I Made Suraharta, 2024). In addition, this study strengthens its conceptual framework by integrating constructivist theory and problem-based learning principles as its primary theoretical foundations. Accordingly, this research is expected not only to provide empirical evidence regarding the effectiveness of STEM but also to contribute to the development of a more holistic, meaningful, and relevant physics learning model aligned with the demands of 21st century education.

Therefore, this study focuses on examining the effect of STEM-based physics learning on students' creativity and problem-solving abilities. The primary objective of this research is to comprehensively analyze the effectiveness of STEM-based learning in enhancing these two competencies among senior high school students.

RESEARCH METHOD

This study employed a quantitative approach using a quasi-experimental method as described by (R. D. Putra et al., 2025), aimed at measuring the magnitude of the effect of STEM-based physics learning on measurable variables, namely students' creativity and problem-solving skills. The quasi-experimental method was selected because full randomization in group assignment was not feasible, as the participants were already organized into naturally formed classes within the school setting (Wastiani et al., 2023). The research design utilized was a pretest–posttest control group design, which aims to examine differences in learning outcomes between the experimental and control groups through measurements conducted before and after the treatment. This design was chosen as it allows for controlling extraneous variables and provides a more accurate representation of students' improvement (Muyassarah et al., 2019; N. Putra et al., 2023).

The participants in this study consisted of 62 tenth-grade high school students, including 31 students from class X IPA 1 as the experimental group and 31 students from class X IPA 2 as the control group. The sampling technique employed was purposive sampling based on the equivalence of initial abilities, as indicated by the average daily physics test scores, which showed no significant difference between the two groups (mean difference < 2 points). Additional considerations included the readiness of laboratory facilities and the availability of technological devices to support the implementation of STEM-based learning (Ridha et al., 2022).

Data were collected using a set of instruments, including a creativity assessment rubric, a problem-solving skills test, and a student activity observation sheet, all of which were validated by two expert lecturers in physics education to ensure content validity (Sailil Hana & Subali, 2023). Instrument reliability was tested through a pilot study involving 30 students outside the research sample using Cronbach's Alpha. The results indicated reliability coefficients of 0.87 for the creativity rubric, 0.84 for the problem-solving test, and 0.82 for the observation sheet, all of which fall into the reliable category (Putri et al., 2020). Data collection procedures included administering pretests and posttests to both groups and conducting observations throughout the learning process.

The implementation of STEM-based physics learning in this study followed a five-phase syntax adapted from Bybee's (2013) model, consisting of reflection, research, discovery, application, and communication, which was designed to promote students' active engagement in integrated scientific and engineering processes (Ataza et al., 2025). The research was conducted through systematic stages, including problem identification, development of instructional materials and research instruments, validation and reliability testing, pretest administration, implementation of learning (the experimental group received STEM-based instruction for six sessions, while the control group received conventional instruction), posttest administration, data analysis, and report preparation (Azizah & Angelina, 2025).

The collected data were analyzed using the N-Gain test to measure the improvement in learning outcomes from pretest to posttest within each group, and the independent sample t-test to determine significant differences between the experimental and control groups (Ardiansyah et al., 2021). Prior to hypothesis testing, data normality was assessed using the Shapiro–Wilk test, and homogeneity of variance was examined using Levene's test. All statistical analyses were conducted using SPSS version 25 with a significance level of $\alpha = 0.05$. The interpretation of N-Gain values followed the criteria proposed by Hake (1999), categorized as high ($g \geq 0.70$), moderate ($0.30 \leq g < 0.70$), and low ($g < 0.30$).

RESULTS AND DISCUSSION

This section presents the research findings based on data obtained from the administration of pretests and posttests in both the experimental and control groups. The findings are systematically organized according to two primary variables, namely student creativity and problem-solving ability, and are subsequently analyzed critically in relation to relevant theoretical frameworks and prior studies. In addition, this section elaborates on statistical interpretations, intergroup comparisons, and the theoretical as well as practical implications of the results.

Based on the analysis of student creativity data, which were measured using an assessment rubric encompassing fluency, flexibility, originality, elaboration, and sensitivity to problems, a substantial improvement was observed in the experimental group. The mean creativity score increased from 61.8 in the pretest to 82.4 in the posttest, reflecting a gain of 20.6 points. In contrast, the control group demonstrated a more modest increase, from 60.5 to 68.2, equivalent to a gain of 7.7 points. Furthermore, the N-Gain value for the experimental group was 0.54, categorized as moderate, whereas the control group only achieved an N-Gain of 0.20, classified as low. These findings indicate that STEM-based learning contributes more significantly to the enhancement of student creativity compared to conventional instructional approaches. This improvement can be attributed to the inherent characteristics of STEM learning, which actively engage students in designing, exploring, and evaluating solutions, thereby directly fostering various dimensions of creativity.

Similarly, students' problem-solving ability, measured through an essay-based test aligned with Polya's problem-solving stages, exhibited a comparable pattern of improvement. The experimental group's mean score increased from 60.3 in the pretest to 79.6 in the posttest, representing a gain of 19.3 points. Meanwhile, the control group showed a smaller increase from 59.8 to 65.8, or a gain of 6.0 points. The N-Gain value for the experimental group reached 0.49 (moderate category), whereas the control group obtained only 0.15 (low category). These results suggest that STEM-based learning effectively enhances students' problem-solving ability. This outcome is consistent with the problem-based nature of the STEM approach, which encourages students to identify authentic problems, analyze relevant variables, devise solution strategies, and systematically evaluate the outcomes, thereby progressively strengthening their cognitive capacities.

Furthermore, inferential statistical analysis using the independent t-test confirmed that the data met the assumptions of normality and homogeneity. The Shapiro–Wilk test indicated that all datasets were normally distributed ($p > 0.05$), while the Levene's test demonstrated homogeneity of variance ($p > 0.05$), thereby justifying the use of parametric testing. The t-test results revealed that the significance value for the creativity variable was 0.001 and for the problem-solving variable was 0.002, both of which are below the threshold of 0.05. Consequently, the null hypothesis was rejected and the alternative hypothesis was accepted, indicating a statistically significant difference between the experimental and control groups. These findings underscore the superiority of STEM-based learning in enhancing both creativity and problem-solving skills.

From a theoretical perspective, the observed improvements in both variables can be explained through constructivist frameworks, particularly those proposed by Piaget and Vygotsky. Within this context, students actively construct knowledge through direct experiences, exploration, and social interaction during the learning process. The process of designing solutions during the discovery phase encourages divergent thinking and the generation of novel ideas, while the use of digital simulations such as PhET in the application phase facilitates deeper conceptual understanding through interactive and visual representations. Moreover, social interaction within small groups reinforces learning through scaffolding and the Zone of Proximal Development, enabling students to achieve higher levels of understanding than they would individually.

The findings of this study are also consistent with several previous investigations. Zulkarnain (2021) reported that STEM-based learning significantly improves students' understanding of physics concepts, while Johri (2022) identified notable gains in critical thinking skills through STEM-based projects. Additionally, Sekar Utami (2020) demonstrated that the STEM approach enhances student engagement and motivation, which indirectly supports the development of creativity. Fadhilah et al. (2021) further revealed that the use of technology-based simulation media in physics learning significantly improves conceptual understanding. Therefore, this study not only corroborates existing findings but also contributes novel insights by demonstrating that STEM-based learning can simultaneously enhance two essential competencies—creativity and problem-solving ability—within an integrated physics learning context.

Practically, this study provides a meaningful contribution to the development of innovative, contextual, and student-centered physics learning models. The implementation of STEM-based learning can serve as an effective pedagogical strategy to improve learning quality and foster 21st century skills. Theoretically, these findings reinforce the premise that constructivist and problem-based learning approaches embedded within STEM yield more meaningful improvements in higher-order competencies compared to conventional instructional methods.

Nevertheless, this study has several limitations that should be acknowledged. The relatively small sample size ($n = 62$) and the short duration of the intervention, which spanned only six sessions, limit the generalizability of the findings. Furthermore, the study was conducted in a single school, thereby restricting its contextual scope. Other variables, such as individual learning styles and students' levels of mathematics anxiety, were not controlled, although they may influence the outcomes. Therefore, future research is recommended to involve larger and more diverse samples, extend the duration of the intervention, and employ longitudinal designs to examine the long-term effects of STEM-based learning in a more comprehensive manner.

CONCLUSION

Based on the results of the study on the implementation of STEM-based physics learning to enhance students' creativity and problem-solving abilities, it can be concluded that this research successfully achieved its intended objectives. Specifically, the study aimed to analyze the effect of STEM-based learning on high school students' creativity and problem-solving skills, and the findings clearly demonstrate its significant impact on both variables.

The results indicate that STEM-based physics learning significantly improves students' creativity, as evidenced by a t-value of 5.41 with a significance level of 0.001 (< 0.05) and an N-Gain score of 0.54, which falls into the moderate category. Similarly, students' problem-solving abilities also showed a statistically significant improvement, with a t-value of 4.87, a significance level of 0.002 (< 0.05), and an N-Gain score of 0.49 (moderate category). Overall, students in the experimental group outperformed those in the control group, demonstrating more substantial and meaningful gains in both creativity and problem-solving skills. These findings confirm that STEM-based learning is more effective than conventional instructional approaches in fostering higher-order competencies.

This study contributes both theoretically and practically to the field of physics education by providing empirical evidence supporting the effectiveness of STEM-based learning in developing essential 21st century skills. Practically, it offers an innovative and student-centered instructional model that can enhance creativity and problem-solving abilities. Theoretically, it reinforces constructivist and problem-based learning frameworks as foundational principles for improving higher-order thinking skills in physics education.

Furthermore, these findings offer broader implications at both national and international levels. At the national level, this research supports the advancement of innovative teaching strategies aligned with the Merdeka Curriculum and contributes to improving the quality of physics education. At the international level, it enriches the global body of literature on STEM education by providing evidence of its effectiveness in enhancing students' higher-order competencies, thereby supporting the development of globally relevant educational practices.

Nevertheless, future research is recommended to expand the scope of the study by involving a larger and more diverse sample across different educational levels and school types. In addition, incorporating mediator variables such as learning motivation and self-efficacy would provide deeper insights into the learning process. The use of mixed-methods approaches is also suggested to further explore the cognitive and affective mechanisms underlying the success of STEM-based physics learning in fostering students' creativity and problem-solving abilities.

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