12 (3) (2023) 110-115

Unnes Science Education Journal

Accredited Sinta 3

https://journal.unnes.ac.id/sju/index.php/usej

The Influence of STEM-based Physics Module to Enhance Critical Thinking Skills

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DOI: http://dx.doi.org/10.15294/usej.v12i3.72443

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Article Info

Submitted 2023-08-03
Revised 2023-10-08
Accepted 2023-11-23

Keywords

critical thinking skills, STEM, module, physics education

Abstract

One effective way of training 21st-century skills, such as critical thinking, is by utilizing the STEM approach to learning. This study aimed to investigate the influence of STEM-based physics modules on the critical thinking skills of 11th-grade students. For this study, the quantitative research method was employed with the research design of a one-group pre-test post-test design. The data was collected from 33 students in a high school in Sukabumi, Indonesia. The researchers developed a module based on STEM principles focused on sound waves, which was then delivered to the students. They were given a pre-test and post-test of five essay questions to assess the student's critical thinking skills. Each question measures each critical thinking skill aspect : elementary clarification, basic support, inference, advanced clarification, and supposition and integration. After analyzing the pre-test and post-test results of the students, Normalized gain calculations were used to measure improvement. The research indicated that the N-gain for the student's critical thinking skills was 0.58, placing it in the medium enhancement category. As a result, it can be concluded that the STEM-based physics module improved the students' critical thinking skills.

How to Cite

Damayanti, E. D., Suwarma, I. R. & Muslim, M. (2023). The Influence of STEM-based Physics Module to Enhance Critical Thinking Skills. *Unnes Science Education Journal*, 12(3), 110-115.

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p-ISSN 2252-6617
e-ISSN 2502-6232

INTRODUCTION

As science and technology progress rapidly, we must adapt and acquire new skills that differ from those required in the past for our global community (Mutohhari et al., 2021). Individual needs to possess the skills known as 21st-century skills, as they are essential for both the present and future. These skills meet society's demands (Benek & Akcay, 2022). The Partnership for 21st Century Skills (P21) organization has developed a comprehensive framework for 21st-century skills (van Laar et al., 2020). P21, which was established in 2002, initiated research on the 21st-century skills required for work, life, and citizenship, including "4C" (Creativity, Communication, Critical thinking, Collaboration) (Ahmed et al., 2015; Sofyana et al., 2021).

Critical thinking skills are currently incorporated into 21st-century education as a required skill for students (Aulia, 2022; Nurfaizah et al., 2022). Critical thinking is logical reasoning to make reasonable predictions or decisions based on what is believed and what has been done (Tiruneh et al., 2017; Zulmaulida et al., 2018). Before deciding on a course of action, a person with critical thinking tends to view problems from multiple viewpoints, consider numerous investigative approaches, and generate countless ideas (Budiarti et al., 2017). Possessing this skill will enable students to effortlessly comprehend and tackle problems across diverse scenarios.

According to Ennis, critical thinking is thinking rationally and reflectively by emphasizing making decisions about what to believe or do (Tiruneh et al., 2017; Zulmaulida et al., 2018). Critical thinking skills are divided into five aspects, each with specific indicators. The critical thinking skills aspects in question are: 1) elementary clarification, 2) basic support, 3) inference, 4) advanced clarification, and 5) supposition and integration. (Aminudin et al., 2019; Puspita et al., 2017).

In order to foster critical thinking skills among students, it is crucial to establish a supportive learning environment that encourages active engagement and development of their potential (Mislia et al., 2019). However, despite the growing recognition of the limitations of the traditional lecture-based teaching approach, many formal education institutions still rely heavily on this method (Calacar & History, 2020). This can be problematic, as passive acceptance of information without critical reflection and analysis may impede the development of students' critical thinking abilities (Flores et al., 2012).

It has become increasingly apparent that students in Indonesia are not adequately equipped with critical thinking skills. This is particularly evident in the sobering statistic that 78% of Indonesian students possess only low-level scientific knowledge, typically consisting of little more than rote memorization and a basic level of understanding (Kurniati et al., 2021). This concerning trend indicates a more significant problem that needs to be addressed to ensure that students are appropriately prepared to navigate the complex challenges of the modern world (Joynes, 2019). Therefore, educators must explore alternative teaching methods prioritizing student-centered learning and promoting critical thinking and problem-solving skills (Kim et al., 2019).

STEM, which stands for Science, Technology, Engineering, and Mathematics, is a learning approach that helps develop critical thinking skills. STEM, which stands for Science, Technology, Engineering, and Mathematics, is a learning approach that helps develop critical thinking skills (Rusilowati, 2020). When using the STEM approach to learning, students will learn about the concept of a material and then apply their knowledge to project activities. This allows students to directly experience the learning process, which aligns with the nature of science (Roberts et al., 2018).

To equip students with the necessary skills for the 21st century, STEM-based learning aims to develop their critical thinking skills (Baran et al., 2021; Yulianti et al., 2022). To enhance critical thinking skills, it is essential to have suitable instructional materials when using the STEM approach for learning (Heryani et al., 2023). Instructional materials are necessary to the curriculum, providing teachers and students with references to aid learning (Bukoye, 2019). In physics, instructional materials rely on traditional books that include definitions, laws and concepts, equations, example problems, and practice problems (Dewi et al., 2018). However, these materials do not adequately promote the development of 21st-century skills.

Integrating STEM into instructional materials has been identified as a viable approach to fostering critical thinking skills in students. Among the common forms of instructional materials that can be employed to achieve this objective are modules. Based on the previous explanation, utilizing STEM-based modules to improve students' critical thinking skills is fitting. By enhancing these skills, students can effectively analyze information and devise solutions to real-world problems, thus producing more knowledgeable

and discerning citizens. This research study is focused on examining the impact of STEM-based physics modules on the enhancement of critical thinking skills among students.

METHOD

A quantitative quasi-experimental study was conducted at a senior high school in Sukabumi, utilizing a one-group pretest-posttest design. The sample was obtained by selecting a single 11th-grade class through a random sampling process. The class consisted of 33 students. The study aimed to investigate the effectiveness of a STEM-based physics module in enhancing students' critical thinking skills. Before implementing the module, the students underwent a pre-test. After implementing the module, a post-test will follow. The assessment for critical thinking skills comprised five essay questions. The pre-test and post-test were conducted to assess any improvements in their critical thinking abilities.

An instrument for evaluating critical thinking skills in sound wave physics has been developed using Ennis' indicators. This instrument assesses five specific aspects of critical thinking skills, including elementary clarification, basic support, inference, advanced clarification, and supposition and integration, with each question addressing one of these aspects.

The critical thinking skills instrument has undergone rigorous testing to ensure its validity and reliability, resulting in successful outcomes. Questions involving advanced clarification received sufficient validation results. While the other aspects, such as elementary clarification, basic support, inference, and supposition and integration, demonstrated high validation rates. Furthermore, the reliability score of 0.70 is considered to be in the high category. The pre-test and post-test results will be analyzed using a normalized gain (N-gain) to evaluate students' critical thinking abilities.

$$\langle g \rangle = \frac{(S_{post}) - (S_{pre})}{(S_{maks}) - (S_{pre})} \quad (1)$$

The results of the N-gain analysis were evaluated by consulting the data presented in Table 1.

Table 1. N-gain Score Criteria

Score <g>	Category
$1 \geq g \geq 0.7$	High
$0.7 > g \geq 0.3$	Medium
$-1 \leq g < 0.3$	Low

RESULT AND DISCUSSION

To measure the improvement of students' critical thinking skills, a test instrument consisting of five essay questions was administered before (pre-test) and after (post-test) applying STEM-based modules. The normalized gain score <g> was used to measure the improvement in critical thinking skills, and the results were analyzed using recognized categories. Table 2 provides an overview of the pre-test and post-test developments for students' critical thinking skills about sound waves following the implementation of STEM-based modules.

Table 2. Results of N-gain for Critical Thinking Skills

Sample	Pre-test	Post-test	N-gain	Category
33	7.15	16.85	0.58	Medium

According to Table 2, the students' pre-test scores averaged 7.15. After using the STEM-based module, the average post-test score increased to 16.85. The average N-gain result for critical thinking skills was 0.58, which falls within the medium category, indicating improved students' critical thinking skills. Therefore, applying STEM-based physics modules has enhanced students' critical thinking skills.

A STEM-based module is an educational tool that aims to enhance students' critical thinking skills by presenting various questions that focus on critical thinking. To better prepare students for the material, the module introduces a series of questions that aid in developing their critical thinking skills. These questions center around everyday occurrences related to sound waves, intending to pique students' interest and promote discussion before commencing class activities. The questions are carefully crafted to assist students in gaining better comprehension of sound wave topics and familiarize themselves with the module's learning objectives. Engaging with these questions encourages students to think critically and develop their analytical skills, ultimately leading to a more enriching educational experience.

This particular STEM module has been meticulously crafted to ensure it adheres to the engineering process and strongly emphasizes hands-on activities and problem-solving as students' primary learning modes. By carefully following the eight crucial stages of the engineering design process outlined by NGSS, students are afforded a highly engaging and meaningful educational experience. These eight stages of learning are 1) Asking questions and defining problems, 2) Developing and using models, 3) Planning and carrying out investigations, 4) Analyzing and interpreting data, 5) Using mathematics and computational thinking, 6) Constructing explanations and designing solutions, 7) Engaging in arguments from evidence, and 8) Obtaining, evaluating, and communicating information. The module also has a comprehensive project integrating each stage into its design.

These projects revolve around everyday issues. Students are tasked with finding solutions to the presented problems, encouraging them to utilize their critical thinking skills. The main objective of this project is to challenge students to think critically and come up with the most appropriate solutions. Participants will be prompted to develop solutions and designs that involve the four STEM aspects of Science, Technology, Engineering, and Mathematics. This will help foster critical thinking and practical application of their skills. Through this project, students receive training on identifying credible sources, observing, drawing conclusions, clarifying information, and determining the best solution or course of action.

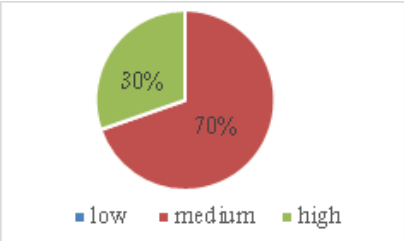

Figure 1. N-gain Percentage of Students' Critical Thinking Skills

Figure 1 presents the N-gain percentage outcomes for all students, which positively impact critical thinking skills. The data reveals that 30% of students achieved high-category improvements, while 70% scored in the medium category. Notably, no students scored in the low category, suggesting that all students witnessed a notable enhancement in their critical thinking skills. Table 3 provides a comprehensive overview of the N-gain outcomes for each aspect of the critical thinking skills evaluated.

Table 3. Results of N-gain for each Critical Thinking Skills Aspect

Aspect	Pre-test	Post-test	N-gain	Category
Elementary clarification	77	98	0.38	Medium
Basic support	30.5	96	0.65	Medium
Inference	38	116	0.83	High
Advance clarification	31	84	0.52	Medium
Supposition and integration	29	66	0.36	Medium

The pre-test results revealed that among the different aspects being assessed, elementary clarifications garnered the highest scores from the students. On the other hand, supposition and integration obtained the lowest scores for the pre-test among the three aspects. Meanwhile, the highest post-test score was in the aspect of inference, and the lowest post-test score was in the aspect of supposition and integration.

It is worth noting that the N-gain values showed varying degrees of improvement. Inference had the highest N-gain value at 0.83, which falls under the high category, indicating that the students showed significant improvement in this aspect. Meanwhile, supposition and integration had the lowest N-gain value at 0.36, which falls under the medium category, indicating moderate improvement.

Using STEM-based physics modules extensively enhanced the students' critical thinking skills. The results demonstrate the benefits of incorporating STEM-based modules in educational programs, particularly in developing students' critical thinking skills, which are essential in their academic and professional pursuits.

CONCLUSION

These findings revealed that incorporating STEM-based physics modules in the learning process can significantly enhance students' critical thinking skills. In this study, the modules focused on sound waves, and the results indicated a moderate improvement in students' normalized gain (N-gain) score, with a value of 0.58. Of particular interest was the inference aspect of critical thinking, which showed the most significant improvement, with an N-gain value of 0.83, indicating a high enhancement level. On the other

hand, the supposition and integration aspects recorded the lowest improvement, with an N-gain value of 0.36, suggesting a medium enhancement level. These findings suggest that while STEM-based modules can effectively promote critical thinking, specific areas may require more attention to ensure optimal results. Although there have been notable advancements in various areas, there remains significant potential for further improvement to achieve optimal levels of enhancement in every aspect of critical thinking skills.

ACKNOWLEDGMENT

The author wishes to express sincere gratitude to all the participants, including the esteemed validators and students, who contributed to the successful completion of this study.

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