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STEM-Based Physics Learning: Enhancing Conceptual Understanding in 21st Century Education

Bahtiar[1*], Ibrahim[2]

[1]Physics Education, Universitas Islam Negeri Mataram, Indonesia
[2]Primary Teacher Education, Universitas Mataram, Indonesia

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Abstract: This research aims to analyze the effectiveness of STEM-based learning in improving the conceptual understanding of prospective physics teachers. The method used was quantitative with a pretest-posttest one-group design, involving 50 students as samples selected purposively. The research instrument consists of 20 multiple choice questions categorized based on cognitive levels C1 to C6. The data analysis technique in this research uses descriptive statistical analysis. The research results show that STEM-based learning increases concept understanding with an average increase of 23.10%, with the minimum score increasing from 30 to 60 and the maximum score from 80 to 90. Analysis based on cognitive level shows the largest increase in C1 (26.0%) and the smallest in C2 (18.5%). These findings indicate that the STEM approach is effective in strengthening students' conceptual understanding and critical thinking skills. Therefore, STEM-based learning is recommended to be implemented in science education to improve the quality of prospective teachers.

Keywords: STEM Learning; Understanding Copncepts; 21st Century Education; Physics Learning.

Introduction

21st century education demands a paradigm shift in learning, especially in the fields of science, technology, engineering and mathematics (STEM) (Granovskiy, 2018; Tytler, 2020; Maass *et al*., 2019). STEM-based physics learning not only focuses on understanding concepts, but also on strengthening critical thinking, problem solving and collaboration skills (Suyatna, 2019; Winarti et al., 2021; Solihin et al., 2021). The application of the STEM approach in physics learning has become a global trend which aims to improve the quality of learning and its relevance to technological developments and industrial needs (Bahtiar et al., 2023).

However, based on a preliminary study conducted on prospective teachers at UIN Mataram, it was found that their conceptual understanding of physics material was still relatively low. From the results of the understanding test of basic physics concepts involving 50 students, only 32% achieved an understanding level above 70%. In addition, interviews with several students showed that the learning methods applied were still conventional with a dominance of lectures and a lack of involvement in experiments or STEM-based projects.

Previous research also shows that the implementation of STEM-based learning can improve students' conceptual understanding. For example, research conducted by Bahtiar et al. (2024) shows that students who study with a STEM approach experience an increase in understanding of concepts by 25% compared to conventional methods. Meanwhile, another study by Apkarian et al. (2021) and Sulaiman et al. (2022) found that integrating STEM in physics

Email: bahtiar79@uinmataram.ac.id

learning can improve critical thinking skills by up to 40%.

The implementation of STEM in physics learning also supports the development of 21st century skills, such as collaboration and communication. A study conducted by Parno et al (2020) shows that students involved in STEM-based projects are better able to work in teams, share ideas, and convey their understanding more effectively. This shows that the STEM approach not only improves cognitive aspects but also social and professional aspects needed in the world of education and industry.

Nationally, the challenges in learning physics in Indonesia are still quite significant. Data from the Ministry of Education, Culture, Research and Technology shows that the results of the National Examination for physics subjects at high school level in the last five years have fluctuated, with the average national score ranging from 45 to 60. The following graph shows the trend of national physics examination scores in the last five years:

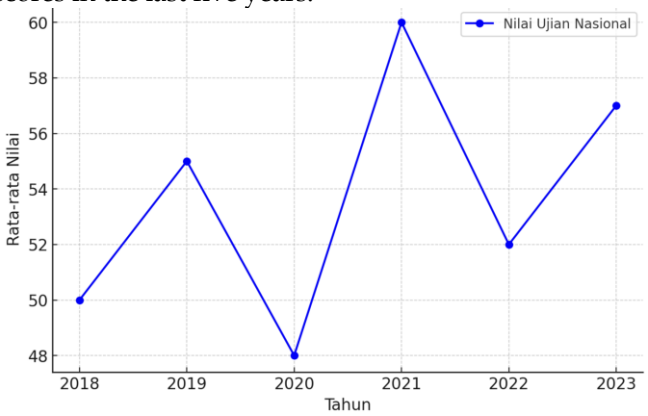

Figure 1. Tren *National Physics Exam Scores in Indonesia 2018-2023*

Additionally, a bibliometric analysis of STEM-related research in physics education shows a significant increase in the last five years. Based on data from Google Scholar and Scopus, the number of publications related to STEM-based physics learning has increased by more than 200% since 2018. The graph below illustrates the trend of research publications in this field:

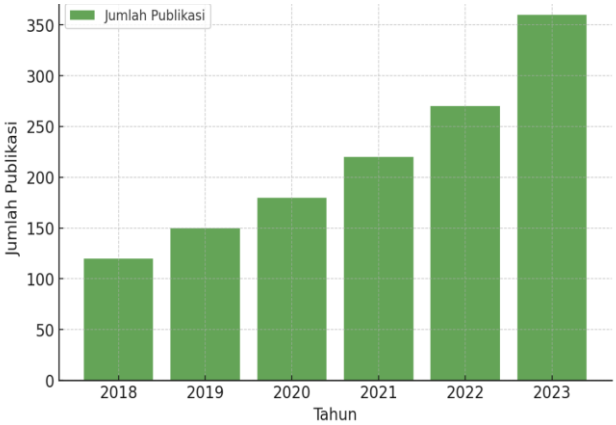

Figure 2. *STEM Research Publication Trends in Physics Learning 2018-2023*

Based on these various findings, this research aims to explore how STEM-based physics learning can improve the conceptual understanding of prospective teacher students. It is hoped that the results of this research can contribute to the development of more effective learning models and increase the readiness of prospective teachers in implementing STEM approaches in their classes in the future.

Thus, this research not only focuses on increasing conceptual understanding, but also on efforts to equip students with 21st century skills that are essential in the world of modern education. Therefore, it is important to develop more innovative and project-based learning strategies so that students can be more active in building their understanding of physics concepts.

Method

This research uses quantitative methods with an experimental approach. The research design applied was a pretest-posttest one-group design, where students were given tests before and after STEM-based learning to see the increase in their understanding of concepts.

The population in this study were 1st semester prospective physics teacher students at UIN Mataram who were taking the Basic Physics course. The research sample consisted of 50 students who were selected using purposive sampling by considering their involvement in this course and their willingness to take part in research. The research procedure is presented in the following figure.

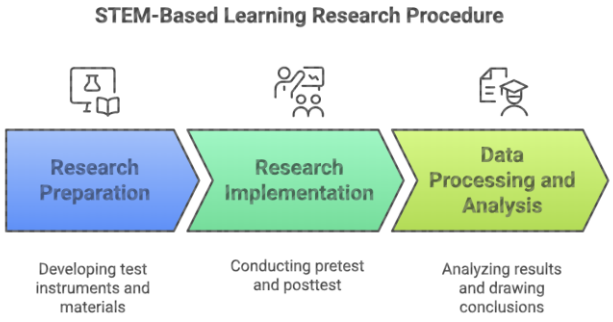

Figure 3. Research Procedure

The research instrument used was 20 multiple choice questions related to kinematics material. These questions are arranged based on cognitive levels from C1 to C6 in order to measure students' overall understanding of the concepts being taught.

The data collection technique in this research was carried out through pretest and posttest. This test aims to measure students' conceptual understanding before and after STEM-based learning. Thus, it can be seen to what extent the STEM approach contributes to increasing student understanding.

The data analysis technique in this research uses descriptive statistical analysis. Data obtained from the pretest and posttest results were analyzed by calculating the average value, standard deviation, and percentage increase in student understanding. The results of this analysis are then interpreted to assess the effectiveness of STEM-based learning on students' conceptual understanding.

Result and Discussion

In this research, an analysis was carried out of prospective teachers' conceptual understanding before and after implementing STEM-based learning. Understanding concepts is a crucial aspect in science education, especially for prospective teachers who will later transfer knowledge to students. Therefore, it is important to know the extent to which the learning approach applied can improve prospective teachers' understanding of concepts. The data in this study was obtained through pretest and posttest, which reflects the level of concept mastery before and after the intervention was carried out. In addition, analysis was carried out based on cognitive levels (C1–C6) to see how each aspect of understanding changed. Data on the distribution of prospective teachers' conceptual understanding scores, both pretest and posttest, are presented in the following figure.

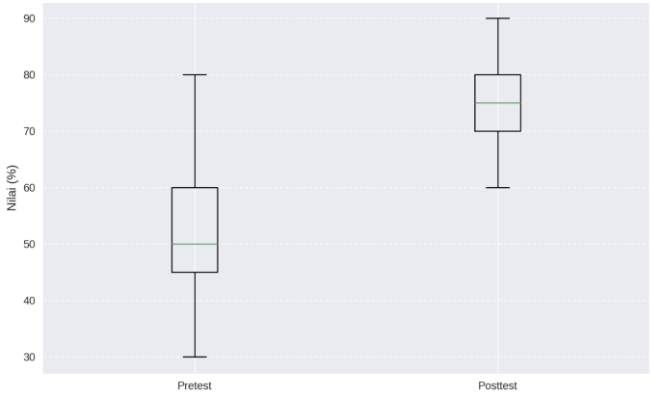

Figure 4. Distribution of Pretest and Posttest Scores

Figure 4 shows the distribution of pretest and posttest scores for prospective physics teacher students after participating in STEM-based learning. Based on the graph, it can be seen that there is a significant increase in the posttest score compared to the pretest. The average pretest score was 51 with a standard deviation of 11.56, while the average posttest score increased to 74.1 with a smaller standard deviation, namely 8.67. Apart from that, the range of scores has also increased, where the minimum score which was previously 30 increased to 60, and the maximum score from 80 to 90. This shows that STEM-based learning is able to increase students' understanding of concepts more evenly.

These results are in line with previous research showing the effectiveness of STEM approaches in improving understanding of 21st century concepts and skills (Ardianti et al., 2020; Nasir et al., 2022; Nasution & Setyaningrum, 2024). A study conducted by Thahir et al. (2020) found that STEM-based learning can increase students' conceptual understanding by 25% compared to conventional methods. Apart from that, Kong & Mohd-Matore (2021) also reported that the application of STEM in physics learning can improve critical thinking skills by up to 40%. This increase is due to the characteristics of STEM learning which is based on exploration, problem solving and knowledge integration, so that students are more active in building their conceptual understanding.

Conceptually, these results can be explained through constructivism theory which emphasizes that conceptual understanding is formed more strongly when students are actively involved in the learning process. A STEM approach based on experimentation and problem solving provides a more meaningful learning experience, allowing students to connect physics concepts with real situations (Simeon et al., 2022; Tan et al., 2023). Thus, the increased understanding demonstrated in the results of this study

supports the importance of applying STEM in physics education to prepare prospective teachers with better skills and understanding to face the challenges of the 21st century (Dare et al., 2021; Samsudin et al., 2020). The results of the frequency of conceptual understanding scores for prospective teachers are also presented in Figure 5 below.

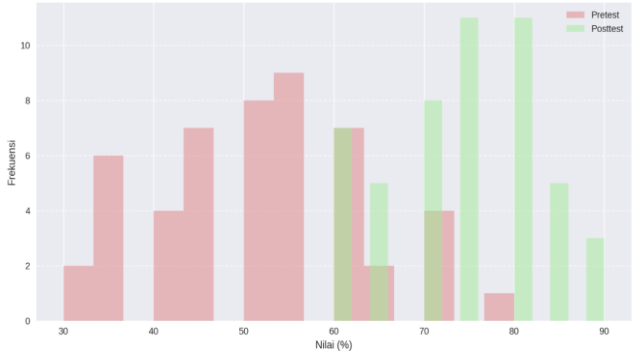

Figure 5. Frequency of Concept Understanding Scores

Figure 5 shows the frequency distribution of students' conceptual understanding scores before and after STEM-based learning. This graph illustrates a shift in the distribution of scores from the pretest (red) to the posttest (green), which indicates an increase in concept understanding. Most pretest scores ranged from 40 to 60, while posttest scores shifted to a higher range, namely 70 to 90. This shows that after participating in STEM-based learning, most students were able to achieve a better understanding of concepts than before learning.

Based on improvement statistics, the average increase in students' conceptual understanding was 23.10%, with a minimum increase of 5% and a maximum increase of up to 45%. The standard deviation of increase of 9.36% indicates that there is variation in the level of increase in understanding among students. These results are consistent with previous research showing that the STEM approach can significantly improve conceptual understanding. Sari et al. (2020) reported that the STEM approach can increase students' conceptual understanding by 25%, while Yang & Baldwin (2020) found an increase in critical thinking skills of up to 40% through a similar method.

From the perspective of constructivist learning theory, this improvement can be explained by the way students build their understanding through active learning experiences. STEM-based learning provides opportunities for students to explore concepts directly through experimentation, problem solving, and knowledge integration (Topsakal et al., 2022). Thus, this approach not only improves conceptual understanding but also helps students develop better critical and analytical thinking skills in understanding basic physics concepts (Yannier et al., 2020; Bancong & Song, 2020). The following also presents a comparison of the results of prospective teachers' conceptual understanding in Figure 4 below.

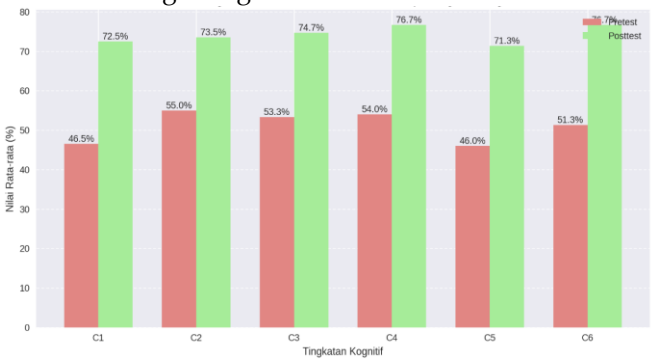

Figure 6. Comparison of Pretest and Posttest Concept Understanding Results

Figure 6 shows a comparison of the average pretest and posttest scores based on cognitive level (C1 to C6). This graph indicates an increase in understanding of concepts at each cognitive level after students participated in STEM-based learning.

At the pretest stage, the average score for all cognitive levels ranged from 46.0% to 55.0%, indicating that before learning, students' understanding of kinematics concepts was still relatively low to moderate. However, after being given STEM-based learning, the posttest results showed a significant increase at all cognitive levels, with scores ranging from 71.3% to 76.7%. The greatest increase was seen at cognitive level C4 (analysis) with an increase from 54.0% to 76.7%, while the smallest increase occurred at C6 (evaluation) from 51.3% to 71.3%.

These results are in line with previous research which shows that STEM-based learning can significantly increase conceptual understanding, especially at higher cognitive levels such as analysis, synthesis and evaluation (Wuladari et al., 2021). This is because the STEM method encourages students to think critically, connect concepts with real situations, and apply knowledge in problem solving.

Based on Bloom's cognitive theory, the increase in higher understanding at levels C4 to C6 shows that STEM-based learning not only helps students understand basic concepts, but also develops their analytical, synthetic and evaluative abilities. Thus, the results of this research support the effectiveness of the STEM approach in increasing students' overall understanding of concepts. Below are also presented the results of increasing understanding of concepts based on prospective teacher indicators.

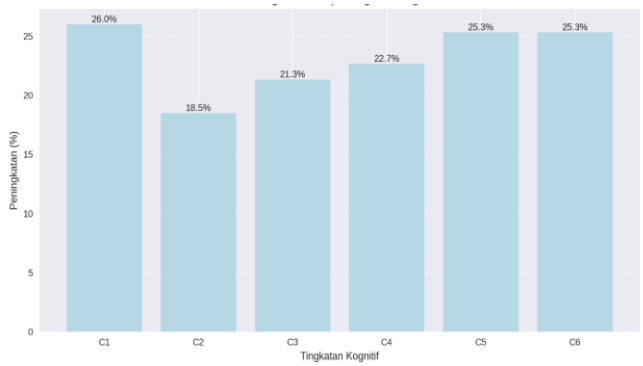

Figure 7. Increased Understanding of Concepts Based on Indicators

Figure 7 shows the increase in concept understanding based on cognitive level (C1 to C6). This graph illustrates the percentage increase in student understanding after being given STEM-based learning. The largest increase occurred at level C1 (remembering) with 26.0%, followed by C5 (evaluation) and C6 (creating) which each increased by 25.3%. The smallest increase occurred in C2 (understanding) with 18.5%. In general, the increase in conceptual understanding is quite evenly distributed at all cognitive levels, indicating that the STEM-based learning approach has a positive impact on improving students' thinking abilities, both at low and high cognitive levels.

These results are in line with previous research which shows that a STEM-based active learning approach can improve students' conceptual understanding and critical thinking skills (Ziatdinov & Valles, 2022; Nguyen et al., 2020). This learning model allows students to be involved in exploring concepts directly, conducting experiments, and connecting theory with practice.

Based on Bloom's taxonomy theory, a significant increase at levels C5 and C6 shows that students not only understand the concept fundamentally, but are also able to analyze, evaluate, and create solutions based on their understanding. Thus, these results strengthen that STEM-based learning is effective in encouraging the development of higher-order thinking skills.

Conclusion

The results showed that STEM-based learning significantly increased prospective teachers' conceptual understanding, with an average increase of 23.10% from pretest to posttest. The minimum value increased from 30 to 60, while the maximum value increased from 80 to 90, indicating an even increase. Analysis based on cognitive level (C1–C6) shows that the greatest improvement occurred at C1 (26.0%), while the smallest increase was at C2 (18.5%), indicating that this approach is effective in strengthening basic understanding while encouraging analytical and creative thinking. These findings support previous research which confirms that STEM methods can improve critical thinking and problem solving skills, so they are recommended for application in science learning for prospective teachers.

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