25 (4), 2024, 1976-1999
Jurnal Pendidikan MIPA
e-ISSN: 2685-5488 | p-ISSN: 1411-2531
http://jurnal.fkip.unila.ac.id/index.php/jpmipa/

Enhancing Students' Critical Thinking Skills and Motivation Using STEM Project-Based Learning (PjBL-STEM) Through a Simple Hydraulic Jack Project

Rudi Hartono, Nanang Winarno*, & Hernani
Department of Science Education, Universitas Pendidikan Indonesia, Indonesia

Abstract: This study presents an investigation of the use of STEM Project-Based Learning (PjBL-STEM) as a treatment in the experimental class compared to conventional learning in the control class in improving students' critical thinking skills and learning motivation. The focus of the study was Pascal's Law lessons with a special project in the form of developing a simple hydraulic jack. So far, science learning carried out in schools has made students complain, as it is still rote, teacher-centered, unrelated to real-life developments, and rarely integrates technology. This study, therefore, used a quantitative method with a quasi-experimental design involving 60 ninth-grade students in Pasaman Regency who were evenly divided into control and experimental classes using purposive random sampling techniques. Data was collected through a questionnaire on critical thinking skills and learning motivation, after the implementation of PjBL-STEM. The results demonstrated a significant difference between the two groups, with an independent T-test yielding a value of 0.24 for critical thinking skills and 0.33 for learning motivation. The PjBL-STEM model has been proven to improve student's critical thinking skills with an N-Gain of 0.46 (moderate category) and students' learning motivation with an N-Gain of 0.49 (moderate category).

Keywords: critical thinking skills, learning motivation, Pascal's Law, PjBL-STEM.

▪ INTRODUCTION

More and more complex challenges are plaguing education in the age of Industry 4.0. Educators must prepare students to face the digitalization of information, such as robotics, artificial intelligence, 3D printing, nanotechnology, biotechnology, the Internet of Things, and others (Baran et al., 2021). In order for students to be able to follow developments dynamically, educators as intermediaries in the teaching process are also required to equip students with 4C skills—creativity, critical thinking, communication, and collaboration (Astawan et al., 2023; Nisah & Syukri, 2024). These skills will prepare students to face the complexities of life and the work environment in order to be able to find solutions to everyday problems and utilize information technology properly (Benek & Akcay, 2022).

More specifically, science education plays a very important role today because part of the growth of society is determined by its scientific skills (Astawan et al., 2023). Despite significant efforts by the Indonesian government to enhance students' proficiency in science, Indonesia's ranking based on PISA results remains low. Among 81 countries, Indonesia ranks 71st for reading, 70th for mathematics, and 67th for science (OECD, 2023). Furthermore, the results of the 2015 Trends in International Mathematics and Science Study (TIMSS) in the field of science placed Indonesia at 44th out of 47 countries (Martin et al., 2016). TIMSS reported that students in Indonesia exhibited weak high-level cognitive skills, such as reasoning, analysis, and evaluation. This adversely affects the low level of critical thinking skills. The findings of the PISA and TIMSS studies

Nanang Winarno
*Email: nanang_winarno@upi.edu
DOI: http://dx.doi.org/10.23960/jpmipa/v25i4.pp1979-1999
Received: 13 January 2025
Accepted: 23 January 2025
Published: 28 January 2025

indicate the low level of critical thinking skills of students, necessitating an enhancement in the quality of education in Indonesia.

Critical thinking encompasses high-level cognitive processes, including analysis, creativity, and reflective thinking, and is recognized as a fundamental skill for the 21st century (Hebebci & Usta, 2022). Critical thinking is an essential skill that students need to acquire, as it significantly contributes to their comprehension of diverse content and real-world issues (Kurniahtunnisa et al., 2023), facilitates systematic and structural problem analysis (Baihaqie et al., 2024), and empowers them to address social, scientific, and practical challenges efficiently (Khaeruddin & Bancong, 2022; Wahdaniyah et al., 2023). Critical thinkers can solve problems logically, provide clear answers to questions, to reasoned conclusions about what to do or believe (Wahdaniyah et al., 2023), and make judgments based on relevant information and facts (Khaeruddin & Bancong, 2022).

In addition to critical thinking skills, learning motivation serves as a prominent factor that impacts student learning outcomes (Hsiao et al., 2024; Pane et al., 2022). Motivated students exhibit greater enthusiasm for exploring the knowledge they acquire, actively working to enhance their skills, and demonstrating a strong sense of curiosity (Pane et al., 2022). Conversely, when students encounter topics that they are unfamiliar with or are not interested in, it will ultimately lead to decreased motivation and desire to learn (Hsiao et al., 2024). Motivation is one of the crucial factors that positively influences achieving student learning outcomes (Dibyantini et al., 2023). Previous studies have reported that students' learning motivation in science subjects still needs significant improvement. Mahanti and Sarkar's (2018) research on science learning motivation in secondary schools indicated that 71.05% of students exhibited average motivation. Additionally, Nuraysha et al. (2024) revealed that ninth-grade junior high school students had moderate science learning motivation, achieving a score of 3.50 out of 5.00. Then, Syauqi et al. (2024) stated in their research results that junior high school students possessed moderate science learning motivation with a score of 3.33 out of 5.00.

Science lessons at the junior high school level are frequently perceived as challenging by students, leading to complaints and a decline in interest in learning. This makes students need greater motivation to learn science. Nonetheless, science learning remains teacher-centered, memorization-based, and less relevant to technological developments and real life. This approach is regarded as less effective in improving students' critical thinking skills. In fact, science learning does not only contain theories and formulas but also requires a deep understanding of various concepts. Science learning facilitates students to develop 4C skills, one of which is critical thinking. Consequently, the learning process is expected to be able to train students to think critically. This skill can be honed when students are given the opportunity to face various problems in real life (Adhelacahya et al., 2023).

Based on observations at school, science learning on the topic of Pascal's Law remains predominantly teacher-centered. Teachers gave more lectures on delivering material before directing students to work on questions from books. As a result, students exhibited passivity, demonstrating minimal involvement in learning activities. Students also encountered difficulty understanding Pascal's Law and applying it in real life, as well as understanding formula equations in problem analysis (Irawati et al., 2022). This has the potential to cause low learning motivation and critical thinking skills in students. Moreover, in the digital era, students' attention is easily diverted by various social media and other technologies. Therefore, students require more interesting and relevant learning to increase active involvement in the science learning process. According to Wahono et al. (2020), one alternative to improving the quality of education is to implement STEM education that combines science, technology, engineering, and mathematics.

The STEM (Science, Technology, Engineering, Mathematics) approach emphasizes a series of student-centered learning and the integration of science, technology, engineering, and mathematics (Baptista & Martins, 2023). STEM can be carried out in formal or informal education, and it involves collaboration across disciplines (Baran et al., 2021). STEM is used to refer to various activities, subjects, or study programs that incorporate one of the four fields, either individually or in an interconnected and integrated manner (Lin et al., 2021).

Students who are accustomed to STEM learning have the skills required for their age, such as problem-solving, critical thinking, and scientific creativity, when confronted with challenging real-world challenges (Anugrah et al., 2023; Hebebci & Usta, 2022). STEM learning can increase students' learning motivation, thus providing a significant positive impact on the development of their affective and cognitive aspects (Han et al., 2023). Based on the results of previous studies, STEM education can improve self-efficacy (Kelley et al., 2020; Samsudın et al., 2020), creativity (Eroğlu & Bektaş, 2022; Shahbazloo & Abdullah Mirzaie, 2023; Yalçın & Erden, 2021), problem-solving (Yalçın & Erden, 2021), reflective thinking skills (Hasançebi et al., 2021), academic success (Eroğlu & Bektaş, 2022; Hiğde & Aktamış, 2022; Shahbazloo & Abdullah Mirzaie, 2023), creative thinking skills (Eroğlu & Bektaş, 2022; Hasançebi et al., 2021), understanding of the nature of science (Eroğlu & Bektaş, 2022), motivation, science process abilities (Hiğde & Aktamış, 2022), 21st-century skills (Benek & Akcay, 2022), inquiry perception and engineering knowledge (Kutlu et al., 2022), cognitive structures (Baptista & Martins, 2023), learning performance, and learning behavior (Hsiao et al., 2024).

One of the learning models that can be implemented with STEM is Project-Based Learning (PjBL). PjBL-STEM is a learning model that implies STEM education based on the PjBL curriculum design (Baran et al., 2021). PjBL-STEM encourages students to examine problems through the integration of STEM into the learning environment. STEM prioritizes student-centered learning, practical activities, teamwork, communication, knowledge construction, and formative assessment as its main components (Samsudın et al., 2020). This focus on student-centered learning allows PjBL-STEM to engage students in more meaningful learning, where new knowledge is gained from real-world experiences and the application of knowledge (Rugh et al., 2021).

Previous studies that have been conducted on the implementation of PjBL-STEM include measuring critical thinking skills (Ashidiq et al., 2024), self-efficacy (Samsudın et al., 2020), design thinking (Lin et al., 2021), 21st-century skills (Baran et al., 2021), concept mastery (Prajoko et al., 2023; Rugh et al., 2021), creativity (Prajoko et al., 2023), as well as science literacy and student learning motivation (Dibyantini et al., 2023). Prior research has also revealed that the implementation of PjBL-STEM significantly increases students' critical thinking skills compared to the PjBL model, especially in science learning with the topic of optical instruments through making handmade projectors (Ashidiq et al., 2024). Another study has shown an increase in student learning motivation for Basic Chemistry Courses on the topic of organic compounds (Dibyantini et al., 2023).

If the research by Ashidiq et al. (2024) previously investigated critical thinking skills using an open-ended essay test instrument developed by Ennis (2018), this current study used a critical thinking questionnaire instrument designed by Marni et al. (2020). The research performed by Ashidiq et al. (2024) employed five indicators of critical thinking, namely basic clarification, basis for decision-making, ability to conclude, further clarification, and rhetorical strategy. These indicators were developed into five open-ended essay questions. Meanwhile, this study discusses four indicators of critical thinking interpreting, analyzing, evaluating, and concluding. These indicators were further developed into 25 questionnaire questions.

Additionally, a prior study by Dibyantini et al. (2023) explored students' learning motivation using a questionnaire instrument with indicators developed by Uno (2014). In contrast, this study adopted a questionnaire instrument with indicators designed by Velayutham et al. (2011). The indicators discussed in Dibyantini et al.'s (2023) study include concentration, enthusiasm, independence, readiness, drive, and self-confidence. These indicators were then formulated into 20 questions to be used for the pre-test and post-test. In this study, learning motivation was analyzed through four main indicators: learning goal orientation, task value, self-confidence, and self-regulation. These indicators were then described in 32 questionnaire questions.

Departing from the explanation above, research on STEM Project-Based Learning has been widely conducted with different findings, samples, and research methods. Hence, the formulations of the research problem are 1) How does PjBL-STEM affect students' critical thinking skills after making a simple hydraulic jack project? Moreover, 2) How does PjBL-STEM affect students' learning motivation after making a simple hydraulic jack project?

▪ METHOD

Research Design

This study employed a quantitative approach with a quasi-experimental model that used a pre-test and post-test control group design. Quantitative research involves evaluating objective hypotheses through the analysis of relationships between measurable variables. This is achieved by using instruments to collect numerical data, which are then analyzed using statistical analysis (Creswell & Creswell, 2022). The quasi-experimental design was chosen because it was difficult to control all external variables, such as student background and learning environment, in this study. According to Creswell and Creswell (2022), a quasi-experimental research design is where the researcher has only limited or no control over the random assignment of participants to levels of manipulated and relevant variables. This study design allows the study to be conducted without the need for complete randomization of participants but still provides valid data to measure the effectiveness of the treatment. In this context, two groups were selected, namely the control group and the experimental group. While the control group was taught with conventional learning, the experimental group was assigned to the STEM Project-Based Learning (PjBL-STEM) model. However, to minimize the influence of external variables, both classes were taught by the same teacher. Then, a pretest was conducted to determine the initial abilities of students in both classes before they were given treatment. The results of the pretest showed that the initial abilities of both classes were almost the same. The quasi-experimental research design is presented in Table 1.

Table 1. The quasi-experimental research design

Group	Pre-test	Treatment	Post-test
Experimental class	O	X	O
Control class	O	-	O

Description:
O: Pre-test and post-test (critical thinking skills and learning motivation)
X: Treatment in the form of STEM Project-Based Learning (PjBL-STEM)

Participants

The purpose of this study was to examine students' critical thinking skills and learning motivation after the implementation of PjBL-STEM on the topic of Pascal's Law. Participants in this study were ninth-grade junior high school students who had never studied the topic of Pascal's Law before. The study was conducted at a public junior high school in Pasaman Regency, with a total of 60 participants aged 14-16 years. Participants were selected using convenience sampling techniques. According to Fraenkel et al. (2011), convenience sampling is a sampling method in which a group of individuals is practically available for research. Convenience sampling is suitable for quasi-experimental designs because it allows researchers to select students from existing classes without randomization. Although complete randomization is not performed, selecting existing classes or groups enables the study to be conducted more quickly and efficiently. This technique allows researchers to conduct experiments in a more natural and realistic environment. Based on this, the control class participants involved Class 9.2 totaling 30 students, consisting of 10 male students and 20 female students. On the other hand, the experimental class participants were taken from Class 9.3 totaling 30 students, comprising 10 male students and 20 female students. The distribution of participants by gender aims to provide an overview of the selected sample but is not discussed further in the study. The distribution of participants is detailed in Table 2.

Table 2. The distribution of participants

Group	Male		Female		Total	
	N	%	N	%	N	%
Experimental class	10	33.3	20	66.7	30	50
Control class	10	33.3	20	66.7	30	50
Total	20	33.3	40	66.7	60	100

Research Instruments

Data collection in this study utilized a questionnaire. For critical thinking skills data, a questionnaire developed by Marni et al. (2020) was used, which was adapted for science learning. According to Marni et al. (2020), the reliability test results show that the study's Cronbach alpha value is 0.862, exceeding the r table (r count > 0.266). This result proves that the instrument can obtain primary data on students' critical thinking skills. This questionnaire consisted of 25 questions covering four indicators, namely interpretation, analysis, evaluation, and inference. The indicators and number of questions in the critical thinking skills questionnaire can be seen in Table 3.

Table 3. The indicators and number of questions about critical thinking skills

Indicators	Item numbers	Number of questions
Interpretation	1. 2. 3. 4. 5. 6. 7. 8	8
Analysis	9. 10. 11. 12. 13. 14. 15. 16	8
Evaluation	17. 18. 19	3
Inference	20. 21. 22. 23. 24. 25	6
Total		25

Moreover, learning motivation was measured using a questionnaire developed by Velayutham et al. (2011). According to Velayutham et al. (2011), the reliability test results show that the study's Cronbach alpha for learning goal orientation (0.91), task value (0.92), self-efficacy (0.92), and self-regulation (0.91). The results show that the Cronbach alpha coefficient for each indicator is more significant than 0.60. This result proves the reliability of the instrument construction in determining students' learning motivation. This questionnaire encompassed 32 questions with four indicators—learning goal orientation, task value, self-efficacy, and self-regulation. Table 4 below displays the indicators and number of questions about learning motivation.

Table 4. The indicators and number of questions about learning motivation

Indicators	Item numbers	Number of questions
Learning goal orientation	1. 2. 3. 4. 5. 6. 7. 8	8
Task value	9. 10. 11. 12. 13. 14. 15. 16	8
Self-efficacy	17. 18. 19. 20. 21. 22. 23. 24	8
Self-regulation	25. 26. 27. 28. 29. 30. 31. 32	8
Total		32

Before being employed, these instruments went through peer review by fellow Science Education Masters students and through expert judgment from two science lecturers. This stage is beneficial for meeting the criteria as a valid instrument. After the implementation of the pre-test and post-test, a statistical test was conducted to analyze students' critical thinking skills and learning motivation. Furthermore, both skills were grouped based on the criteria in Tables 5 and 6 below.

Table 5. Critical thinking skills scoring criteria

Critical Thinking Interval	Criteria
$X > 88$	Very critical
$56 < X \leq 88$	Critical
$36 < X \leq 56$	Critical enough
$8 < X \leq 36$	Less critical
$X \leq 8$	Not critical

Table 6. Learning motivation scoring criteria

Interval of motivation	Criteria
$86 \leq X \leq 100$	Very motivated
$72 \leq X < 86$	Motivated
$58 \leq X < 72$	Sufficiently motivated
$44 \leq X < 58$	Less motivated

$30 \leq X < 44$	Not motivated

Research Procedures

Pre-test-post-test control group design was used in this study with three main stages, i.e., determination, implementation, and completion. In the determination stage, the study began with the identification and formulation of the problem, followed by a literature study related to the STEM approach, Project-Based Learning STEM, critical thinking skills, and student learning motivation in science learning. Afterward, the preparation of instruments, conducting peer reviews, validation by expert judgment, and revisions according to input were carried out. The last step of this stage was to prepare learning tools, namely the lesson plan (RPP), learning media, and student worksheets.

Following that, the implementation stage was carried out on ninth-grade junior high school students for four meetings. For the experimental class, at the first meeting, a pre-test was conducted to measure students' initial abilities and the preparation stage for implementing STEM-based projects. At the second meeting, it was continued with the implementation stage and proceeded with presentation activities at the third meeting. The fourth meeting was filled with evaluation and improvement and a post-test to measure the final results of students' critical thinking skills and learning motivation. Meanwhile, for the control class, at the first meeting, a pre-test was conducted to test students' initial abilities. The second and third meetings were carried out using conventional learning. In the fourth meeting, the discussion of questions and implementation of the post-test continued. Details of activities in the implementation stage, in addition to the PjBL-STEM pre-test and post-test, are summarized in Table 7.

The final stage of this research was the completion stage. At this stage, data analysis was performed using statistical methods to obtain research results. Based on this analysis, the researchers drew conclusions, which were then compiled in the form of a scientific paper.

Table 7. Activities in the experimental class with PjBL-STEM

Stages	Activities
Preparation Stage	Students discussed the given problems. Students explored information related to solutions to problems related to Pascal's Law. Students learned about the project theme and scope of Pascal's Law and a simple hydraulic jack.
Implementation Stage	Students discussed the need for tools and materials. Students made a simple hydraulic jack.
Presentation Stage	Students tested the product, which consisted of measuring the diameter of the syringe, the length of the hose, and the mass of the load lifted. Each group presented their product and the basic concept behind it.
Evaluation Stage	Students conducted peer evaluations of other groups' products. The teacher provided evaluations of students' products.
Correction Stage	Students made corrections to their products based on suggestions and feedback. Next, students began to revise the simple hydraulic jack based on previous suggestions.

▪ RESULT AND DISSCUSSION

The Influence of PjBL-STEM on Students' Critical Thinking Skills

Students' critical thinking skills were measured twice in the control and experimental classes. The first test, known as the pre-test, was administered prior to therapy, and the second was given following treatment, called the post-test. The study was conducted on the pre-test and post-test at a public junior high school in Pasaman Regency.

The critical thinking skills indicators used in this study were adopted from Marni et al. (2020), including interpretation, analysis, evaluation, and inference. These indicators were then developed into 25 questionnaire questions using a Likert scale. The questionnaire was employed to collect data on student's critical thinking skills in the experimental and control classes. The pre-test and post-test data on students' critical thinking skills were further analyzed utilizing SPSS version 27, with a summary of the values that can be seen in Table 8.

Table 8. Summary of students' critical thinking skills scores

Group	Test	N	Mean	SD
Control Class	Pre-test	30	82.30	6.75
	Post-test	30	84.66	8.74
Experimental Class	Pre-test	30	79.74	9.81
	Post-test	30	89.90	6.21

In the control class, the average pre-test score was 82.30 (SD 6.75), with a critical category, and the average post-test score was 84.66 (SD 8.74), with a critical category, based on the critical thinking category in Prayogi and Yuanita (2018). Meanwhile, in the experimental class, the average pre-test score was 79.74 (SD 9.81) with a critical category, and the average post-test score was 89.90 (SD 6.21) with a very critical category. The average scores before and after the application of the treatment in both classes showed an increasing trend. This finding is further explained by the results of the lowest and highest scores, which demonstrated the same increasing trend in the experimental and control classes. The average scores of students' critical thinking skills during the pre-test and post-test in both classes are presented in Figure 1.

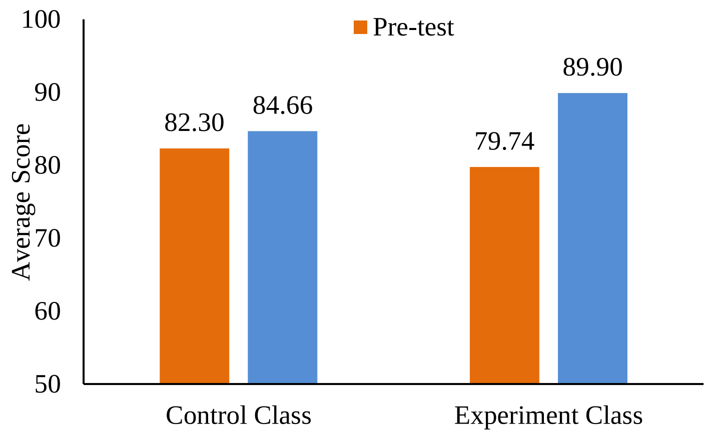

Figure 1. Average score of critical thinking skills

Figure 1 strengthens the research results in Table 8, showing a tendency to increase the average value of critical thinking skills achieved by students before and after undergoing treatment. Thus, it can be interpreted that the application of treatment in learning is effective in improving students' critical thinking skills.

To support the findings and interpretations above, normality and homogeneity tests were required. More valid conclusions can be drawn from normally distributed and homogeneous samples or populations. The normality test in this study was taken from the Shapiro-Wilk test, and the homogeneity test used the Levene test. The pretest and posttest results of both classes were subjected to a normality test and homogeneity test. The students' questionnaire answers were converted into numbers and analyzed using the SPSS version 27 application. The normality results are shown in Table 9.

Table 9. The normality test of critical thinking skills

Group	Test	Normality Test (Shapiro-Wilk)	Interpretation
Control Class	Pre-test	0.99	Normal
	Post-test	0.69	Normal
Experimental Class	Pre-test	0.35	Normal
	Post-test	0.12	Normal

Based on Table 9, the outputs of the normality test (Shapiro-Wilk test) in the control class were 0.99 for the pre-test results and 0.69 for the post-test results. In comparison, the results of the normality test in the experimental class were 0.35 for the pre-test and 0.12 for the post-test. A value of more than 0.05 indicates that the data were normally distributed. Next, the value of the homogeneity test of students' critical thinking results is summarized in Table 10.

Table 10. The homogeneity test of critical thinking skills

Test	Class	Homogeneity Test (Levene test)	Interpretation
Pre-test	Control class	0.08	Homogenous
	Experimental class		
Post-test	Control class	0.07	Homogenous
	Experimental class		

According to Table 10, the results of the homogeneity test (Levene's test) were 0.08 for the pre-test and 0.07 for the post-test. The homogeneity test indicated a result exceeding 0.05, signifying that the data group originated from a population with homogeneous variance. Next, parametric analysis is carried out to determine how likely a difference between independent group data is. The independent t-test can be used for parametric analysis based on the normality test and homogeneity test, which show that both classes are normally and homogeneously distributed. The value of one sample does not provide any insight into the values of the other samples. The outcomes of this test are explained in Table 11.

Table 11 indicates that the independent T-test yielded outputs of 0.24 for the pre-test results and 0.01 for the post-test results. In the pre-test results, students in both classes had not studied Pascal's Law. In contrast to the pre-test results, the post-test results revealed that both classes had studied Pascal's Law material. The post-test results had a

Table 11. Independent T-test of critical thinking skills

Test	Class	Mean	Independent t-test Significance (2-tailed)	Interpretation
Pre-test	Control class	82.30	0.24	No significance
	Experimental class	79.74		
Post-test	Control	84.66	0.01	Significant
	Experiment	89.90		

significance level of 0.05, leading to the rejection of the null hypothesis (H0). This value explains a notable difference between the control class and the experimental class after being given treatment. The implementation of the PjBL-STEM learning procedure in the experimental class is the reason for this outcome. In addition, to ensure the similarity of the recorded data and maintain the integrity and accuracy of the data, Cohen's d-effect size test and the N-Gain test were carried out. In Cohen's d effect size test in the control class and the experimental class, a value of 0.69 was obtained, indicating an effect within the moderate category.

Subsequently, to find out the value of the increase in each group, an N-Gain or Normality Gain test was conducted based on Hake (1998). The N-Gain of students' critical thinking skills in the control class with conventional learning increased by 0.09. In the experimental class, through the implementation of PjBL-STEM, students' critical thinking skills also increased with an N-Gain value of 0.46. The N-Gain values in the control and experimental classes exhibited an increasing trend, as illustrated in Figure 2.

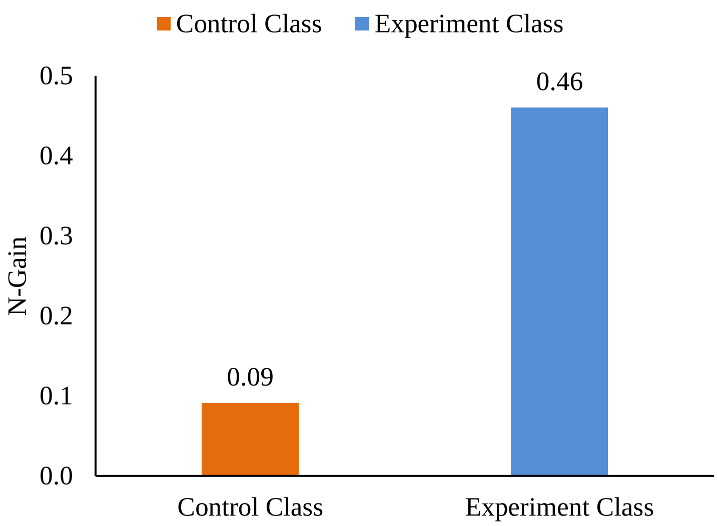

Figure 2. N-Gain students' critical thinking skills

Figure 2 interprets that the application of conventional learning in the control class improved students' critical thinking skills at a low level. Meanwhile, the application of PjBL-STEM in the experimental class was shown to be effective in improving critical thinking skills at a moderate level. To find out further effects, the N-Gain of each indicator of critical thinking skills could also be determined with the same procedure. The indicators of critical thinking skills discussed in this study encompassed interpretation, analysis, evaluation, and inference. The N-Gain of students' critical thinking skills in each indicator is depicted in Figure 3.

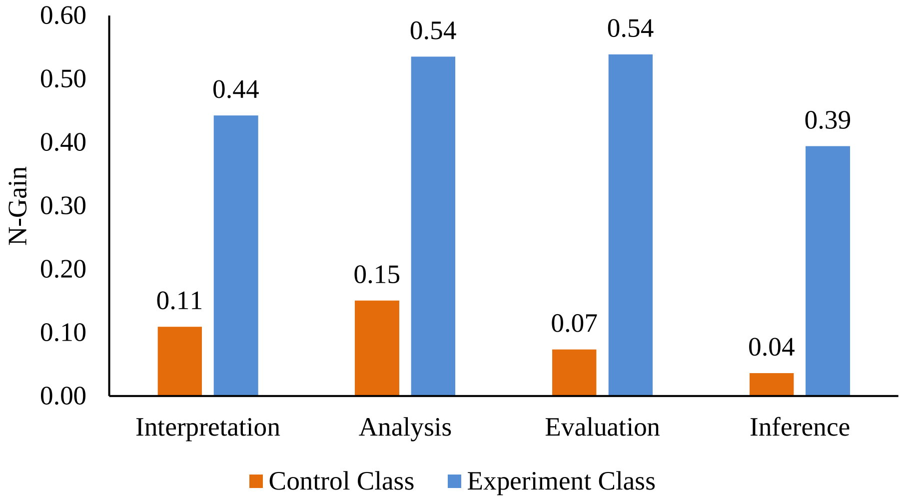

Figure 3. N-Gain of each critical thinking skill indicator

As illustrated in Figure 3, the evaluation indicator exhibited the most significant difference in N-Gain between the control and experimental classes. Conversely, the interpretation indicator displayed the least significant difference in indicators. In the control class, the N-Gain obtained was in the low category for all indicators, whereas in the experimental class, all indicators had N-Gain in the moderate category. Hence, overall, the experimental class's implementation of PjBL-STEM significantly influenced the development of students' critical thinking skills, as evidenced by all indicators of critical thinking skills. In PjBL-STEM learning, students were directed to provide alternative solutions to solve problems in everyday life. This problem was then analyzed, and students sought a solution by making a simple hydraulic jack. This activity allows for better interpretation and analysis indicators than conventional learning. PjBL-STEM students conduct product trials and evaluations based on teacher and friend suggestions, improving evaluation skills. Then, student activities in selecting the tools and materials used and making improvements to the hydraulic jack product improve inference skills.

This suggests that STEM Project-Based Learning had a moderately positive effect on the development of students' critical thinking skills in the aspects of interpretation, analysis, evaluation, and inference. STEM Project-Based Learning has the potential to significantly enhance students' critical thinking skills in comparison to conventional learning. This increase is due to the fact that the hydraulic jack project in the experimental class on the topic of Pascal's Law could train students' critical thinking skills.

The Influence of PjBL-STEM on Student Learning Motivation

In this study, students' learning motivation was assessed using a questionnaire in the pre-test and post-test activities for both classes (control and experiment). The learning motivation indicators employed in this study were adopted from Velayutham et al. (2011), namely learning goal orientation, task value, self-efficacy, and self-regulation. These indicators were then developed into 32 questions using a Likert scale. After the data were collected through the questionnaire, a statistical test was conducted to determine students' learning motivation in the control and experimental classes. A summary of students' learning motivation is presented in Table 12.

Table 12. Summary of learning motivation scores

Group	Test	N	Mean	SD
Control Class	Pre-test	30	85.44	7.48
	Post-test	30	87.21	6.57
Experimental Class	Pre-test	30	83.33	8.94
	Post-test	30	91.54	6.31

As Table 12 details, in the control class, the average pre-test score was 85.44 (SD 7.48) in the motivated category, and the average post-test score was 87.21 (SD 6.57) in the highly motivated category. In the experimental class, the average pre-test score was 83.33 (SD 8.94) with the motivated category, and the average post-test score was 91.54 (SD 6.31) with the highly motivated category. The average scores recorded before and after the application of the treatment in both classes demonstrated an increasing trend. This finding is further clarified by the lowest and highest scores in both classes, which exhibited the same increasing trend. The average score of students' learning motivation in both classes is shown in Figure 4.

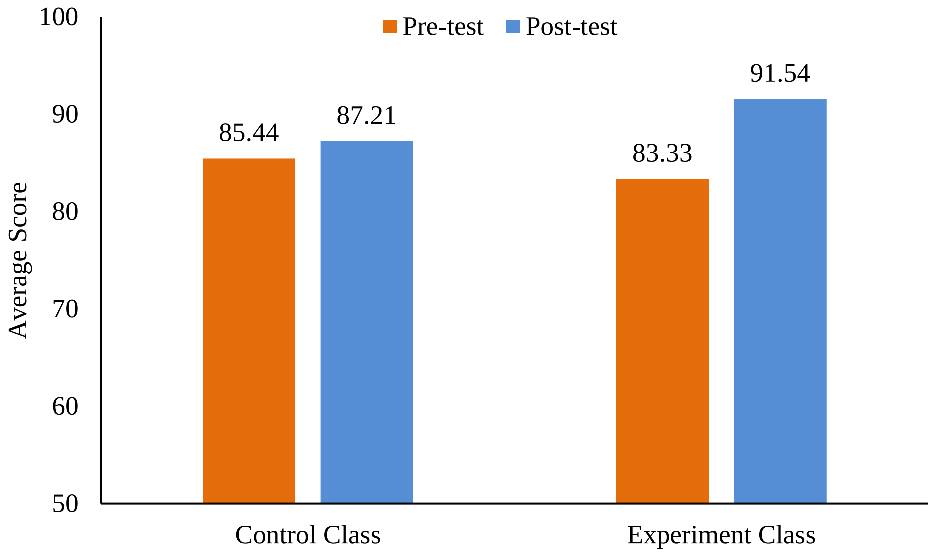

Figure 4. Average score of learning motivation

Figure 4 illustrates a tendency to increase the average value of learning motivation achieved by students from before to after following the treatment. Consequently, the treatment in learning activities is effective in enhancing student learning motivation. Furthermore, homogeneity and normality tests were carried out using the Shapiro-Wilk test and Levene's test. Table 13 displays the outcomes of the normality test for learning motivation values.

Table 13. The normality test of learning motivation

Group	Test	Normality Test (Shapiro-Wilk)	Interpretation
Control Class	Pre-test	0.07	Normal
	Post-test	0.36	Normal
Experimental Class	Pre-test	0.23	Normal
	Post-test	0.14	Normal

Based on Table 13, the normality test results in the control class were 0.07 for the pre-test results and 0.36 for the post-test results. Meanwhile, in the experimental class, the values obtained were 0.23 for the pre-test and 0.14 for the post-test. These values indicate more than 0.05, suggesting that the data were normally distributed. In addition, a homogeneity test was carried out on the results of learning motivation in the control and experimental classes, which are presented in Table 14.

Table 14. The Homogeneity test of learning motivation

Test	Class	Homogeneity Test (Levene test)	Interpretation
Pre-test	Control class	0.60	Homogenous
	Experimental class		
Post-test	Control class	0.80	Homogenous
	Experimental class		

As indicated in Table 14, the homogeneity test values for the pre-test results were 0.60 and for the post-test results were 0.80. The data set was derived from a population with a homogeneous variance, as evidenced by the homogeneity test values exceeding 0.05. Moreover, to ascertain how likely there was a difference between independent group data, the independent t-test was implemented. Table 15 provides an explanation of the results of this test.

Table 15. Independent T-test of learning motivation

Test	Class	Mean	Independent t-test Significance (2-tailed)	Interpretation
Pre-test	Control class	85.44	0.33	No significance
	Experimental class	83.33		
Post-test	Control class	87.21	0.00	Significant
	Experimental class	91.54		

The output of the independent T-test presented in Table 15 indicates a value of 0.33 for the pre-test results and a value of 0.00 for the post-test results. The significance level value after studying Pascal's Law yielded a value below 0.05, indicating that the null hypothesis (H0) was rejected. This value demonstrates a notable disparity between the control class and the experimental class in the post-test following the treatment administered. The observed difference could be attributed to the implementation of the PjBL-STEM procedure within the learning process of the experimental class. In addition, the Cohen's d effect size test was used to see the extent of the influence of PjBL-STEM on learning motivation. The Cohen's d effect size test yielded a value of 0.67 when comparing the control class to the experimental class, indicating a moderate effect size.

Further, the results of the N-Gain test demonstrated that student learning motivation through the application of conventional learning in the control class increased by 0.04. Then, in the experimental class, through the application of PjBL-STEM, an N-Gain value of 0.49 was obtained. The N-Gain values in the control and experimental classes are shown in Figure 5.

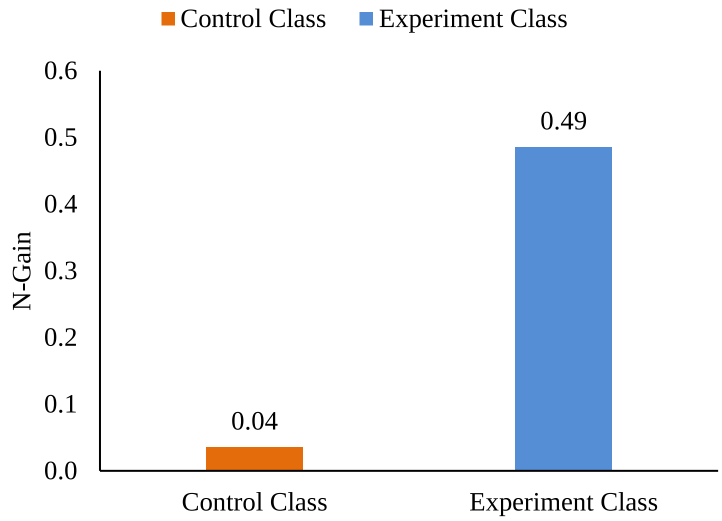

Figure 5. N-Gain students’ learning motivation

In Figure 5, it can be interpreted that the application of conventional learning in the control class increased students' learning motivation at a low level. In comparison, the application of PjBL-STEM effectively increased students' learning motivation at a moderate level in the experimental class. This result is due to the difference in treatment in the control class and the experimental class. With the same procedure, the N-Gain of each learning motivation indicator could also be determined. The learning motivation indicators discussed in this study included learning goal orientation, task value, self-efficacy, and self-regulation. The N-Gain of students' learning motivation in each indicator is displayed in Figure 6.

Figure 6 reveals that the N-Gain of all indicators was in the low category in the control class that implemented conventional learning. Meanwhile, the experimental class that implemented PjBL-STEM exhibited N-Gain values that were classified as moderate for all indicators. This increase suggests that all indicators play a substantial role in the development of student learning motivation. While the indicator of orienting learning objectives exhibited a very significant difference in N-Gain between the control and experimental classes, the task value indicator exhibited the least difference in indicators. Product creation in PjBL-STEM learning improves students' assignment scores compared to conventional learning. Creating a hydraulic jack that is highly relevant to engineering and real-life contexts. In product creation, students had to search for information about simple hydraulic jacks on the Internet or in science books. Project planning improves students’ ability to orientate learning goals and self-regulation. Furthermore, students’

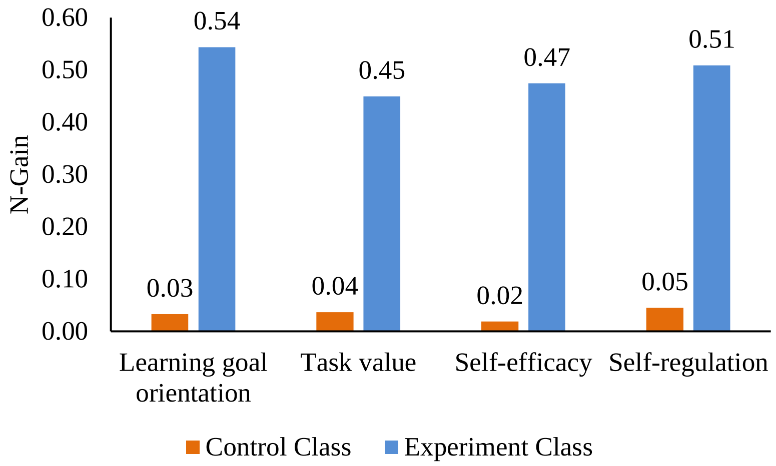

Figure 6. N-Gain of each learning motivation indicator

success in creating a functioning hydraulic jack and presenting their products can increase their self-efficacy.

In this study, students made a simple hydraulic jack based on the STEM approach. The integration of STEM in the activity of making a simple hydraulic jack is presented in Table 16.

Table 16. Integration of STEM in the making of hydraulic jacks

STEM Learning Approach			
Science (S)	**Technology (T)**	**Engineering (E)**	**Mathematics (M)**
Identifying the application of the concept of pressure and Pascal's Law in hydraulic jacks	Finding information from the Internet, deciding on materials and tools, and testing the performance of the hydraulic jack.	Creating a simple and effective hydraulic jack design	Calculating output force

Table 16 illustrates the context of STEM integration in this study. Teachers should determine this context at the beginning of STEM implementation in classroom learning. In this study, the Science (S) aspect focuses on exploring the application of Pascal’s law to a hydraulic jack. Before designing a simple hydraulic jack, students were asked to understand the concept of pressure and its relationship to Pascal's Law. A deep understanding of the relationship between surface area and pressure allows students to choose the appropriate syringe size to create a simple hydraulic jack. In this process, students are expected to determine the appropriate syringe diameter at the input and output so that the hydraulic jack can lift heavier loads safely.

The technology (T) component was integrated in various stages. In the preparation stage, students utilized online resources or scientific literature related to Pascal's Law and the types of hydraulic jacks to be made for problem-solving. This stage also involved the selection of tools and materials and the steps for making a simple hydraulic jack. Furthermore, the technology element was applied in the implementation stage, where students tested and validated the performance of their homemade hydraulic jack through direct practice.

The engineering aspect (E) plays a significant role in the preparation and implementation phases. Students designed a design that aligns with Pascal's Law. The detailed design facilitated the construction process by including important information, such as the diameter of the syringe and the length of the hose. Meanwhile, the mathematical involvement (M) focused on calculating the output force generated by the simple hydraulic jack made by the students. Students used relevant formulas to calculate the output force generated by their hydraulic jack.

Starting from the preparation stage, students explored initial knowledge about the problems given with the help of student worksheets, found solutions to problems, created product designs, and determined tools and materials through group discussions. In PjBL-STEM learning, students were directed to provide alternative solutions to solve problems in everyday life. At this stage, the researcher provided several examples of simple hydraulic jack products that students could make. The STEM approach to learning can train students cognitively, skillfully, and effectively. In addition, students were taught in theory and practice so that they could directly experience the learning process (Prajoko et al., 2023). After that, students began to discuss project planning in groups. In this process, students had to search for information related to simple hydraulic jacks on the Internet or in science books. Project planning trained students' ability to orientate learning goals and self-regulation. Therefore, the researcher included some information and guiding questions in the student worksheet to help students achieve their targets.

From that information, students would gain experience in determining the cause of the problem and solving problems encountered in everyday life. The problem that arose in this study was people with difficulty lifting objects (cars), which were presented with student worksheet guidance. This problem was then analyzed, and students sought a solution by making a simple hydraulic jack. The selection of the type of hydraulic jack, limited tools and materials, and the amount of load that the hydraulic jack can lift were challenges for students in producing products. Hence, the preparation stage is crucial at the beginning of STEM Project-Based Learning. The purpose of the preparation stage is not only to make tools but also to trigger students' initial knowledge of the topic, fulfill student group assignments, determine materials, and create product designs for each group. During the preparation stage, students were given the opportunity to explore problems and obtain the information needed to solve problems, both from books and the Internet. This stage could help students develop their critical thinking skills, especially in interpreting and analyzing indicators. Critical thinking skills can be improved when students try to find innovative solutions through product design to solve real-life problems (Baran et al., 2021). From the results of this exploration, students create projects in groups to overcome these problems in order to be more enthusiastic about designing projects (Kurniahtunnisa et al., 2023).

In the implementation stage, students were asked to design a simple hydraulic jack and prepare the necessary materials based on the design that had been made. During the implementation stage, students engaged in practical experiments to realize their project design and start making a simple hydraulic jack. In addition, they conducted actual testing to ensure the functionality and capabilities of their homemade hydraulic jack. Critical thinking skills can develop through direct experiments and collaborative discussions among students (Ijirana et al., 2022). In the process of making a hydraulic jack during the implementation stage, students had to make decisions about the choice of the type of hydraulic jack, the choice of tools and materials, and the method of manufacture. Here, critical thinking skills allowed them to consider how each choice affected the performance of the resulting hydraulic jack. They analyzed problems theoretically, solved problems, and designed innovative solutions to ensure that the simple hydraulic jack worked effectively. Students made their designs into actual products, as disclosed in Figure 7.

Figure 7. Simple hydraulic jack made by students

The next stage was the presentation stage, where students shared tasks to direct the presentation, provide explanations, answer questions, if any, and provide conclusions about the projects they made. At the presentation stage, students tried to communicate their product designs and results. Students also expressed the problems they faced while working on the project. In presenting, students had to think critically about how to attract attention when presenting the product. The product presentation is presented in such a way that it is communicative and easy to understand (Sumarni & Kadarwati, 2020). This presentation stage also trained students to increase their self-efficacy. Self-efficacy helps students understand their chances of success in learning and helps them avoid feelings of inability to complete learning objectives (Raisah et al., 2023). In addition, at this stage, students also conducted actual trials of their products. In conducting product trials, the challenges given at the beginning of the project made students more motivated to display their products. The results of the students' simple hydraulic jack product trials are revealed in Table 17.

Table 17. Product trial results at presentation stage

Group	Diameter 1 (Input) (mm)	Diameter 2 (Output) (mm)	Hose length (cm)	Load mass successfully lifted (gr)
1	22	32	60	0
2	32	22	30	70
3	32	22	40	60

4	32	22	38	0
5	32	22	38	50
6	32	22	30	890

In the evaluation stage, each group, with teacher guidance, evaluated their project based on discussions, insights, or arguments from other groups. At this stage, students' critical thinking skills were explored. In addition, at the correction stage, each group of students corrected or revised their product-making project by replacing the syringe with a different diameter or replacing the materials used. This activity gave them a new understanding of the factors affecting their project performance. This stage also trained self-regulation aspects, where students had to be able to stay focused on their project when receiving feedback and not give up easily, and each group also had to complete their product on time.

During the evaluation and correction stage, students made improvements to the products that had been made. This stage served as a reflection material for students to find the best way to improve product quality. Effective learning should provide opportunities for students to reflect on their own critical thinking, receive feedback from other students, and revise their thinking as a result of new information freely. Effective learning should also provide opportunities for students to evaluate scientific evidence based on their own understanding, connect theories with their own explanations, and participate in learning. In this instance, students' critical thinking contributed to creating effective solutions to improve students' products. The aspect of task value, one of the indicators of learning motivation, also played a role in providing the best solution for the expected product. The hydraulic jack developed by students, along with its measurement data post-improvement, can be seen in Figure 8 and Table 18.

Figure 8. Student-made hydraulic jack after correction

Table 18. Product results after correction

Group	Diameter 1 (Input) (mm)	Diameter 2 (Output) (mm)	Hose length (cm)	Load mass successfully lifted (gr)
1	22	32	60	1,100
2	22	32	30	2,100
3	22	32	20	100

4	22	32	38	2,100
5	22	32	38	1,750
6	32	22	30	1,350

This study found that the treatment of STEM Project-Based Learning (PjBL-STEM) effectively improved students' critical thinking skills compared to conventional learning. This can be seen from the results of the independent t-test, showing that the level of significance was 0.24 for the pre-test results and 0.01 for the post-test results. The pre-test results exhibited a significance level beyond 0.05, whereas the post-test data demonstrated a significance level below 0.05. The significance value indicates a conclusion, signifying that the null hypothesis (H0) was rejected. This finding implies a significant difference between the control class and the experimental class after the post-test.

These results are also supported by the N-Gain comparison, showing an increase in every aspect of students' critical thinking skills. The application of PjBL-STEM in the experimental class obtained an N-Gain value of 0.46, which means that it was at a moderate level. Simultaneously, the control group employing conventional learning achieved an N-Gain value of 0.09, indicating a low level. This suggests that the PjBL-STEM model is more appropriate for improving critical thinking skills. The results of this study align with previous studies stating that the STEM project-based learning model can improve students' critical thinking skills and concept mastery (Ashidiq et al., 2024). The difference in treatment the PjBL-STEM experimental class and the conventional learning control class is the cause of this result. This is also consistent with previous studies, which indicate that the PjBL-STEM model affects critical thinking skills.

Numerous related studies indicate that the learning model is one of the factors that influence students' critical thinking skills, particularly through the implementation of PjBL-STEM, which can help students improve their critical thinking skills (Ashidiq et al., 2024; Baran et al., 2021; Kurniahtunnisa et al., 2023; Nisah & Syukri, 2024). This is because learning is contextual and meaningful. This discussion also aligns with the constructivism learning theory proposed by Piaget and Vygotsky. Constructivism emphasizes that students can obtain active knowledge through direct experience (Jonassen, 1991). The constructivist concept can be implemented through PjBL-STEM at the preparation stage when students identify problems. At this stage, students are given real-world issues that require critical thinking to analyze problems and plan solutions. Constructivism is also seen in the application and presentation stages, where students must analyze information on tool and material needs, design designs, and test products. This process encourages students to think critically, identify problems, and test solutions.

The integration of aspects of science, technology, engineering, and mathematics with various stages of group projects makes students more active in the learning process (Kurniahtunnisa et al., 2023). In PjBL-STEM activities, students are involved in all parts of the process, from the preparation stage to the improvement stage. By following the stages and reducing the number of trial-and-error opportunities, students exercise greater caution and are less prone to mistakes. Students exert greater effort to maximize the efficiency of each phase of the project (Rugh et al., 2021). The application of PjBL-STEM in this study offers distinct benefits since students also studied Pascal's Law material. This suggests that students know not only the concept of Pascal's Law but also its mechanism and application in real life. This finding is also pertinent to previous research on the topic of light and optics. The study found that the increase in students' critical thinking skills in the aspects of basic clarification, advanced clarification, and rhetorical strategies in the experimental class was better than in the control class (Ashidiq et al., 2024).

Furthermore, learning with the PjBL-STEM model makes students creative and develops their critical thinking skills in solving problems (Kurniahtunnisa et al., 2023). The STEM approach encourages students to apply scientific and other knowledge to design solutions. This knowledge can create a supportive environment for fostering creativity, where students are encouraged to think, explore and play independently, observe and reflect, and ask unusual questions (Shahbazloo & Abdullah Mirzaie, 2023).

PjBL-STEM also has a better influence on students' learning motivation. PjBL-STEM can improve all aspects of learning motivation, namely concentration, enthusiasm, independence, readiness, drive, and self-confidence (Dibyantini et al., 2023). A simple hydraulic jack project can increase students' learning motivation in STEM project-based learning. This project encourages students to relate theoretical knowledge to real-world applications. By seeing the real results of a working hydraulic jack, students better understand the learning objectives and master associated concepts. The steps in STEM also make students feel satisfied with their practical performance, confident in their ability to perform better, interested in the material presented, and acquire interdisciplinary knowledge and skills. Students learn how to combine real-world challenges and interdisciplinary knowledge and use tools to practice ideas and knowledge (Hsiao et al., 2024).

The project also clearly assigns students a value by creating a hydraulic jack that is highly relevant to engineering and real-life contexts. PjBL helps complete work and principles related to practice (Chang & Chen, 2022). The hands-on practice in this project is beneficial in increasing students' self-efficacy. As students begin to see progress in assembling the hydraulic jack, they will feel more confident about continuing and completing the project. In addition, the STEM approach can increase students' self-confidence, encouraging students to build knowledge concepts through observation activities, investigations, and asking some questions they want to know (Raisah et al., 2023). Team collaboration in PjBL-STEM also supports self-regulation, as students must work together to achieve project goals. They need to communicate, divide tasks, and provide constructive feedback to each other to manage tasks more efficiently.

▪ CONCLUSION

Based on the results of this study, in the experimental class implementing PjBL-STEM, students' critical thinking skill scores were obtained with an average of 89.90, while the control class with conventional learning reached an average of 84.66. Students learning motivation in the experimental class exhibited an average of 91.54, while in the control class, the average obtained was 87.21. In addition, the application of the PjBL-STEM model resulted in an N-Gain of students' critical thinking skills of 0.46 and an N-Gain of students' learning motivation of 0.49, both of which were included in the moderate increase category. In comparison, in the conventional learning model, the N-Gain of students' critical thinking skills was 0.09, and the N-Gain of students' learning motivation was 0.04, both categorized as low increases. These results indicate that STEM project-based learning positively impacted students' critical thinking skills and learning motivation.

Additionally, some implications for the effectiveness of the STEM approach provide benefits in this study. This study provides important insights into one of the ways to implement the STEM approach, i.e., the PjBL-STEM model. Although efforts have been made to link the impact of PjBL-STEM on students' critical thinking skills and learning motivation, the analysis of each stage of PjBL-STEM related to both aspects remains inadequate to gain a deep understanding. As such, this study recommends that science teachers continue to develop critical thinking skills and improve students' learning motivation through various means. The implementation of PjBL-STEM is one alternative to achieve this beneficial combination. In addition, PjBL-STEM is useful for students to solve their daily life problems.

▪ ACKNOWLEDGMENTS

The author would like to thank the Higher Education Financing Agency (BPPT), Ministry of Education, Culture, Research, and Technology, Republic of Indonesia, which has provided an opportunity through the Indonesian Education Scholarship (BPI) program. This program has provided significant financial, moral, and academic support in reinforcing the author's research.

▪ REFERENCES

Adhelacahya, K., Sukarmin, S., & Sarwanto, S. (2023). The impact of problem-based learning electronics module integrated with STEM on students’ critical thinking skills. Jurnal Penelitian Pendidikan IPA, 9(7), 4869–4878.

Anugrah, A., Herlina, K., & Suyatna, A. (2023). Inquiry-Integrated STEM on electronic student worksheet: an effort to stimulate creative thinking and collaborative skills. Jurnal Ilmiah Pendidikan Fisika Al-Biruni, 12(2), 251–263.

Ashidiq, R. M., Winarno, N., Prima, E. C., Widodo, A., & Chang, C.-Y. (2024). Investigating the Impact of STEM learning on students’ critical thinking skills through hand-made projector activity. Journal of Science Learning, 7(2), 187–203.

Astawan, I. G., Suarjana, I. M., Werang, B. R., Asaloei, S. I., Sianturi, M., & Elele, E. C. (2023). STEM-Based scientific learning and its impact on students’ critical and creative thinking skills: an empirical study. Jurnal Pendidikan IPA Indonesia, 12(3), 482–492.

Baihaqie, A. G., Kurniasih, D., Kurniawan, R. A., & Nufus, Z. (2024). Boosting critical thinking with stem-based nanolearning in reaction rate studies. Jurnal Penelitian Pendidikan IPA, 10(8), 6132–6141.

Baptista, M., & Martins, I. (2023). Effect of a STEM approach on students’ cognitive structures about electrical circuits. International Journal of STEM Education, 10(1), 15.

Baran, M., Baran, M., Karakoyun, F., & Maskan, A. (2021). The influence of project-based STEM (PjbL-STEM) applications on the development of 21st century skills. Journal of Turkish Science Education, 18(4), 798–815.

Benek, I., & Akcay, B. (2022). The effects of socio-scientific STEM activities on 21st century skills of middle school students. Participatory Educational Research, 9 (2), 25–52. International Journal of Education in Mathematics Science and Technology, 7(1), 32–52.

Chang, C.-C., & Chen, Y.-K. (2022). Educational values and challenges of i-STEM project-based learning: A mixed-methods study with data-transformation design. Frontiers in Psychology, 13, 976724.

Creswell, J. W., & Creswell, J. D. (2022). Research design: qualitative, quantitative, and mixed methods approaches. SAGE Publications. https://books.google.co.id/books?id=Rkh4EAAAQBAJ

Dibyantini, R. E., Amdayani, S., Siregar, M. I., & Syafriani, D. (2023). Application of STEM-PjBL based chemistry module to improve science literacy and student learning motivation. Jurnal Penelitian Pendidikan IPA, 9(SpecialIssue), 95–102.

Ennis, R. H. (2018). Critical thinking across the curriculum: A vision. Topoi, 37, 165–184.

Eroğlu, S., & Bektaş, O. (2022). The effect of 5E-based STEM education on academic achievement, scientific creativity, and views on the nature of science. Learning and Individual Differences, 98, 102181. https://doi.org/10.1016/j.lindif.2022.102181

Fraenkel, J., Wallen, N., & Hyun, H. (2011). How to design and evaluate research in education. In Journal of American Optometric Association (Vol. 60).

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. American Journal of Physics, 66(1), 64–74.

Han, J., Kelley, T., & Knowles, J. G. (2023). Building a sustainable model of integrated stem education: Investigating secondary school STEM classes after an integrated STEM project. International Journal of Technology and Design Education, 33(4), 1499–1523.

Hasançebi, F., Güner, Ö., Kutru, C., & Hasancebi, M. (2021). Impact of Stem integrated argumentation-based inquiry applications on students' academic success, reflective thinking and creative thinking skills. Participatory Educational Research, 8(4), 274–296.

Hebebci, M. T., & Usta, E. (2022). The effects of integrated STEM education practices on problem solving skills, scientific creativity, and critical thinking dispositions. Participatory Educational Research, 9(6), 358–379.

Hiğde, E., & Aktamış, H. (2022). The effects of STEM activities on students' STEM career interests, motivation, science process skills, science achievement and views. Thinking Skills and Creativity, 43, 101000. https://doi.org/10.1016/j.tsc.2022.101000

Hsiao, H.-S., Chen, J.-H., Chang, T., Li, P.-H., & Chung, G.-H. (2024). A Study on the effects of using the 6e model and a robot teaching assistant on junior high school students' stem knowledge, learning motivation, and hands-on performance. Journal of Science Education and Technology, 1–20.

Ijirana, I., Aminah, S., Supriadi, S., & Magfirah, M. (2022). Critical thinking skills of chemistry education students in team project-based STEM-metacognitive skills learning during the Covid19 pandemic. JOTSE, 12(2), 397–409.

Irawati, R. K., Sofianto, E. W. N., Assidiqi, H., & Rahmawati, I. (2022). Pascal or archimedes: which misconception is higher? Journal of Physics: Conference Series, 2392(1), 12030. https://doi.org/10.1088/1742-6596/2392/1/012030

Jonassen, D. H. (1991). Objectivism versus constructivism: Do we need a new philosophical paradigm? Educational Technology Research and Development, 39, 5–14.

Kelley, T. R., Knowles, J. G., Holland, J. D., & Han, J. (2020). Increasing high school teachers self-efficacy for integrated STEM instruction through a collaborative community of practice. International Journal of STEM Education, 7, 1–13.

Khaeruddin, K., & Bancong, H. (2022). STEM education through PhET simulations: An effort to enhance students' critical thinking skills. Jurnal Ilmiah Pendidikan Fisika Al-Biruni, 11(2), 34–45.

Kurniahtunnisa, K., Anggraito, Y. U., Ridlo, S., & Harahap, F. (2023). STEM-PjBL learning: the impacts on Students' critical thinking, creative thinking, communication, and collaboration Skills. Jurnal Penelitian Pendidikan IPA, 9(7), 5007–5015.

Kutlu, E., Bakırcı, H., & Kara, Y. (2022). STEM education effect on inquiry perception and engineering knowledge. Participatory Educational Research, 9(3), 248–262.

Lin, K.-Y., Wu, Y.-T., Hsu, Y.-T., & Williams, P. J. (2021). Effects of infusing the engineering design process into STEM project-based learning to develop preservice technology teachers' engineering design thinking. International Journal of STEM Education, 8, 1–15.

Lou, S.-J., Chou, Y.-C., Shih, R.-C., & Chung, C.-C. (2017). A study of creativity in CaC2 steamship-derived STEM project-based learning. Eurasia Journal of Mathematics, Science and Technology Education, 13(6), 2387–2404.

Mahanti, J., & Sarkar, S. (2018). A study on motivation of high school students towards science learning. International Journal of Research and Analytical Reviews, 5(3), 138–142.

Marnı, S., Alıman, M., & Harsıatı, T. (2020). Students' critical thinking skills based on gender and knowledge group. Journal of Turkish Science Education, 17(4), 544–560.

Martin, M. O., Mullis, I. V. S., Foy, P., & Stanco, G. M. (2016). TIMSS 2015 International results in science. Retrieved from Boston College, TIMSS & PIRLS International Study Center. http://timssandpirls.bc.edu/timss2015/international-results/

Nisah, K., & Syukri, M. (2024). Optimizing of Physics Learning through PjBL-STEM model to improve critical thinking skills and students responsibility attitudes. Jurnal Penelitian Pendidikan IPA, 10(4), 1770–1778.

Nuraysha, A. D., Winarno, N., Fadly, W., Hakim, L., & Emiliannur, E. (2024). Analyzing student's motivation towards science learning in junior high school. Jurnal Penelitian Pendidikan IPA, 10(7), 4139–4148.

OECD. (2023). PISA 2022 Results (Volume I): The state of learning and equity in education. OECD Publishing. https://doi.org/10.1787/53f23881-en

Pane, E. P., Manurung, H. M., Simangunsong, A. D., Mobo, F. D., Siahaan, T. M., & Manurung, S. (2022). The effect of stem-based learning module on students learning outcomes and motivation in general chemistry courses. IJECA (International Journal of Education and Curriculum Application), 5(2), 211–218.

Prajoko, S., Sukmawati, I., Maris, A. F., & Wulanjani, A. N. (2023). Project based learning (pjbl) model with stem approach on students' conceptual understanding and creativity. Jurnal Pendidikan IPA Indonesia, 12(3), 401–409.

Prayogi, S., & Yuanita, L. (2018). Critical inquiry based learning: a model of learning to promote critical thinking among prospective teachers of physic. Journal of Turkish Science Education, 15(1), 43–56.

Raisah, P., Rahmatan, H., & Safitri, R. (2023). Implementation of STEM-Based learning modules containing islamic values to improve student learning outcomes and motivation. Jurnal Penelitian Pendidikan IPA, 9(SpecialIssue), 1400–1401.

Rugh, M. S., Beyette, D. J., Capraro, M. M., & Capraro, R. M. (2021). Using DIME maps and STEM project-based learning to teach physics. Interactive Technology and Smart Education, 18(4), 553–573.

Samsudın, M. A., Jamalı, S. M., Zaın, A. N. M., & Ebrahım, N. A. (2020). The effect of STEM project based learning on self-efficacy among high-school physics students. Journal of Turkish Science Education, 17(1), 94–108.

Shahbazloo, F., & Abdullah Mirzaie, R. (2023). Investigating the effect of 5E-based STEM education in solar energy context on creativity and academic achievement of female junior high school students. Thinking Skills and Creativity, 49, 101336. https://doi.org/https://doi.org/10.1016/j.tsc.2023.101336

Sugiyono. (2014). *Metode penelitian pendidikan pendekatan kuantitatif, kualitatif dan R&D.* Alfabeta.

Sumarni, W., & Kadarwati, S. (2020). Ethno-stem project-based learning: Its impact to critical and creative thinking skills. Jurnal Pendidikan IPA Indonesia, 9(1), 11–21.

Syauqi, S. K., Winarno, N., Samsudin, A., Damopolii, I., & Firdaus, R. A. (2024). From online to in-person: Students' motivation and self-regulation in science teaching activities during and after the covid-19 pandemic. INSECTA: Integrative Science Education and Teaching Activity Journal, 5(1), 87–107.

Uno, H. B. (2014). *Teori Motivasi dan Pengukurannya: analisis di bidang pendidikan.*

Velayutham, S., Aldridge, J., & Fraser, B. (2011). Development and validation of an instrument to measure students' motivation and self-regulation in science learning. International Journal of Science Education, 33(15), 2159–2179.

Wahdaniyah, N., Agustini, R., & Tukiran, T. (2023). Analysis of Effectiveness PBL-STEM to improve student's critical thinking skills. IJORER: International Journal of Recent Educational Research, 4(3), 365–382.

Wahono, B., Chang, C.-Y., & Retnowatı, A. (2020). Exploring a direct relationship between students' problem-solving abilities and academic achievement: A STEM education at a coffee plantation area. Journal of Turkish Science Education, 17(2), 211–224.

Yalçın, V., & Erden, Ş. (2021). The Effect of STEM activities prepared according to the design thinking model on preschool children's creativity and problem-solving skills. Thinking Skills and Creativity, 41, 100864. https://doi.org/10.1016/j.tsc.2021.100864