Jurnal Penelitian Pembelajaran Fisika
Vol. 16 Issue 3 – July 2025, p252-260
p-ISSN 2086-2407, e-ISSN 2549-886X
Available Online at http://journal2.upgris.ac.id/index.php/JP2F
DOI: 10.26877/jp2f.v16i3.1879

Enhancing Students' Critical Thinking Skills on the Alternative Energy Topic in Junior High School Through Integrated STEM-PjBL Model

Julia Nur Aini[1,2], **Heni Rusnayati**[1] **and Ida Kaniawati**[1]
[1]Program Studi Pendidikan Fisika, FPMIPA, Universitas Pendidikan Indonesia Jalan Dr. Setiabudi No. 229, Bandung, Jawa Barat 40154 Indonesia

[2]E-mail: juliaaini@upi.edu

Received: 11 April 2025. Accepted: 25 June 2025. Published: 31 July 2025.

Abstract. Critical thinking ability is a fundamental ability that every graduate must have in order to be able to adapt to technological and social changes in the 21st century. The aim of this research is to determine the increase in students' critical thinking abilities after learning using the STEM (Science, Engineering, Technology and Mathematics) integrated Project Based Learning learning model. The method used was pre-experiment with a one-group pretest-posttest design. The sample for this research was 30 class VIII students in one of the Bandung City Middle Schools. The sampling technique was carried out using a purposive sampling technique. The instruments used were critical thinking ability tests, student worksheets, student response questionnaires and learning implementation observation sheets. Increased critical thinking was analyzed using N-Gain with an N-Gain value of 0.6306 in the medium category, and students' responses to learning showed positive results. From these results, it was found that the application of the STEM (Science, Technology, Engineering and Mathematics) integrated Project Based Learning learning model can improve students' critical thinking abilities. Based on the results of the discussion, the implications of learning using the Project Based Learning model integrated with STEM (Science, Technology, Engineering and Mathematics) have a significant influence on students' critical thinking skills.

Keywords: project based learning, STEM, critical thinking skills

1. Introduction

Education must adopt a learning approach that emphasizes dynamic processes, in order to increase students' curiosity about their surroundings. One of the most important aspects in the world of education is critical thinking, this skill is a basic skill to be able to solve a problem. Critical thinking comes from a process of ability based on the results of analysis and evaluation of an existing problem [1]. Critical thinking patterns can provide ideas logically, reflectively, productively and seek an opinion and argument. To develop students' critical thinking skills, it is necessary to implement good learning strategies [2]. One of them is the Project Based Learning (PjBL) model." According to the Ministry of Education and Culture, PjBL is "A learning model that involves projects in the learning process." [3]. This model gives students the opportunity to choose learning activities that suit their needs is a "learning model that uses projects or activities as a means to achieve competence in attitudes, knowledge and skills".

In conventional classes, educators act as experts who teach students new knowledge, concepts and skills. In contrast, in Project Based Learning, students are given the freedom to choose what they want to learn and how they will do it [4]. Tan & Chapman state that "The Project Based Learning model places the center of learning in the process of asking questions that direct students to understand the concepts and principles related to the material they are studying" [5]. Through project-based learning,

students are given the freedom to explore various disciplines to solve problems, while also giving them space to explore their own potential [*6*].

This model emphasizes the application of critical thinking in learning, where students are actively involved in completing projects [7]. "Apart from the model, a relevant approach is needed. One approach that can be integrated with the PjBL model is the STEM (Science, Technology, Engineering, and Mathematics) approach." "The application of the STEM approach will help to realize educational theory material into a reflective activity and is supported through practices that support STEM aspects [8]. Improving critical thinking skills can be done through the PjBL-STEM model [9]. PjBL (Project Based Learning) is a learning model, while STEM is a learning approach. Other research by Kurniawan Arif Maspul found that learning that combines PjBL and STEM provides an interactive experience that can helps students develop their critical thinking skills[10]. Research by Aan also states that with PjBL-STEM learning, students can be more active in learning activities and can find their own ideas [11].

There are five steps in PjBL-STEM learning, with specific process achievement steps: 1) Reflection: Inviting students to face a problem and providing encouragement to investigate and solve it. 2) Research: Collecting information from various relevant sources. 3) Discovery: Connecting the research stage with application in designing project designs. 4) Application: Testing a product or solution to solve a problem. 5) Communication: Presenting the results of the project or solutions that have been found. By conveying to friends and the class about a product he made [12].

According to [13]"STEM must be integrated into an educational process that focuses on solving problems in the real world." Learning with a STEM-based approach can create a unified learning system because these four aspects are needed simultaneously by students to solve problems. A STEM-based learning approach is designed to encourage students to be able to independently or with little help, analyze their learning needs, set learning goals, identify learning resources, select and implement appropriate strategies, and evaluate their own learning achievements [14].

Therefore, it can be concluded that the STEM approach is an approach that integrates various scientific disciplines and can help students to improve their thinking processes which helps them understand and connect the four aspects of this approach [15]. The STEM approach also applies aspects of it to real life. This can encourage students to take the initiative and think critically in solving a problem [16]

Based on this background, this research aims to improve students' critical thinking skills by implementing a Project Based Learning learning model that is integrated with STEM (Science, Technology, Engineering, and Mathematics). It is hoped that this learning model can improve students' critical thinking skills, so that they can solve problems, especially in alternative energy material on the topic of wind energy, with a clearer and deeper understanding.

2. Method

In this research, the method used is a quantitative method. In this study, the population studied were students in grade VIII at one of the junior high schools in Bandung. The selection of this population was based on the researcher's real experience during the *Kampus Mengajar* program. In this research, the sampling technique used was purposive sampling, the sample taken in this research was one class from class VIII, totaling 30 people, in one of the junior high schools in Bandung City. The data collection instruments used in this research consisted of test questions, namely pretest and posttest in the form of 10 description questions, as well as non-test questions in the form of learning implementation observation sheets which were filled in by observers during the learning process to assess the implementation of the STEM integrated PjBL model. Apart from that, a student response questionnaire was also used to determine students' responses to the learning experience using this model.

2.1. *Learning Implementation Analysis*

The implementation of learning is evaluated through observation sheets filled in by observers during the teaching and learning process. This observation sheet covers various indicators, including the stages in the PjBL model as well as STEM elements. The score will be calculated using the following equation:

$$Percentage = \frac{Amount\ of\ learning\ carried\ out}{Total\ amount\ of\ learning} \times 100\ \% \quad (1)$$

Table 1. Learning Implementation Criteria.

Implementability Learning	Criteria
0.00 ≤ 1.75	Irrelevant
1.76 ≤ 2.50	Less Suitable
2.51 ≤ 3.25	Good
3.26 ≤ 4.0	Very Good

2.2. *Analysis of Improving Critical Thinking Ability*

Evaluation of the increase in students' critical thinking skills is carried out by comparing the results of the pretest and posttest after implementing the PjBL learning model which is integrated with STEM. The level of increase is analyzed using the N-Gain test, which is calculated using the following formula:

$$N - Gain = \frac{Posttest\ Score - Pretest\ Score}{Maximum\ Score - Pretest\ Score} \quad (2)$$

Table 2. N-Gain Acquisition Categories.

N-Gain Value	Criteria
g > 0.70	High
0.70 ≥ g ≥ 0.30	Average
g < 0.30	Low

2.3. *Analysis of Student Response Questionnaires*

Analysis of student response questionnaires was carried out to support data related to student perceptions regarding the implementation of the Project Based Learning learning model which is integrated with STEM. This questionnaire is measured using a Likert scale with the following conditions:

Table 3. Likert Scale of Student Questionnaire Responses.

	Scale	
Criteria	Positive Statements	Negative Statements
Strongly Agree	4	1
Agree	3	2
Disagree	2	3
Strongly Disagree	1	4

$$\%\ Responses = \frac{Obtained\ Score}{Total\ Score} \times 100\% \quad (3)$$

The assessment results are categorized based on Table 4.

Table 4. Assessment criteria.

Presentase	Kriteria
81% - 100%	Very Good
61% - 80%	Good
41% - 60 %	Good Enough
21% - 40%	Less Good
0% - 20%	Very Not Good

3. Results and Discussion

Data on students' critical thinking abilities was obtained from the pretest and posttest results, then analyzed using the N-Gain test. Next, a normality test was applied to determine whether the pretest and posttest data were normally distributed. This test was carried out using IBM SPSS 27 with Shapiro-Wilk analysis, because the amount of data was less than 50. The results of the normality test are shown in Table 5.

Table 5. Results of Normality Test using Shapiro-Wilk.

	Statistic	df	Sig.
Pretest	0.235	30	<0.001
Posttest	0.157	30	0.111

Based on the results of the normality test using Shapiro-Wilk analysis, the significance value for the pretest and posttest shows a sig. < 0.05. This indicates that the data is not normally distributed, so hypothesis testing is continued with Wilcoxon test analysis. The Wilcoxon test is a non-parametric statistical method used when the normal distribution assumption is not met. This test aims to determine whether there is a significant difference between the pretest and posttest results in measuring students' critical thinking abilities. Wilcoxon test analysis was carried out using IBM SPSS 27 software, and the results of data processing are presented in Table 6.

Table 6. Wilcoxon test results. Information a = *Posttest* < *Pretest*, b = *Posttest* > *Pretest*

	N	Mean Rank
Negative Ranks	0[a]	0.00
Positive Ranks	30[b]	15.50

Based on the results obtained, the value obtained is smaller than 0.05. Therefore, it can be concluded that the hypothesis is accepted. This shows that there is a difference between the pretest and posttest results after implementing the STEM integrated PjBL model on alternative energy material, especially wind energy, at the junior high school level.

The results of increasing students' critical thinking abilities through the STEM integrated PjBL learning model can be known by calculating the normalized N-Gain from the pretest and posttest score data on students' critical thinking abilities and can be seen in Table 7.

Table 7. Overall N-Gain analysis results.

	Grade Average	<g>	Criteria
Pretest	15.38		
Posttest	65.91	0.6360	Medium

Based on the results in Table 6, the N-Gain value obtained is 0.6360, which is in the range $0.70 \geq g \geq 0.30$, so it is categorized as a moderate increase. The N-Gain value in this range is included in the medium category. These findings indicate that the application of the STEM integrated PjBL learning model is effective in improving students' critical thinking abilities.

The increase in students' critical thinking skills for each indicator was analyzed through pretest and posttest using 10 essay questions that discussed alternative energy material on the topic of wind energy. The questions consist of 2 items for indicators providing simple explanations, 2 items for building basic skills, 3 items for drawing conclusions, 2 items for providing further explanations, and 1 item for organizing strategies and tactics. An increase in students' critical thinking skills occurred in every aspect before and after being given treatment, as shown in Table 8.

Based on the Table 8, the gain test results for each indicator of critical thinking ability show variations in two categories, namely high and medium. Indicators providing simple explanations, building basic skills, drawing conclusions and providing further explanations have N-Gain values in the range $0.70 \geq g \geq 0.30$, so they are in the "medium" category. Meanwhile, the indicator for managing strategy and tactics has an N-Gain ($g \geq 0.70$), which is included in the "high" category.

Table 8. Results of N-Gain test for each indicator of students' critical thinking skills.

Indicators of Critical Thinking Ability	Gain Average	Criteria
Provide a Simple Explanation	0.58	medium
Building Basic Skills	0.54	medium
Drawing Conclusions	0.61	medium
Provide Further Explanation	0.63	medium
Setting Strategy and Tactics	1.00	high

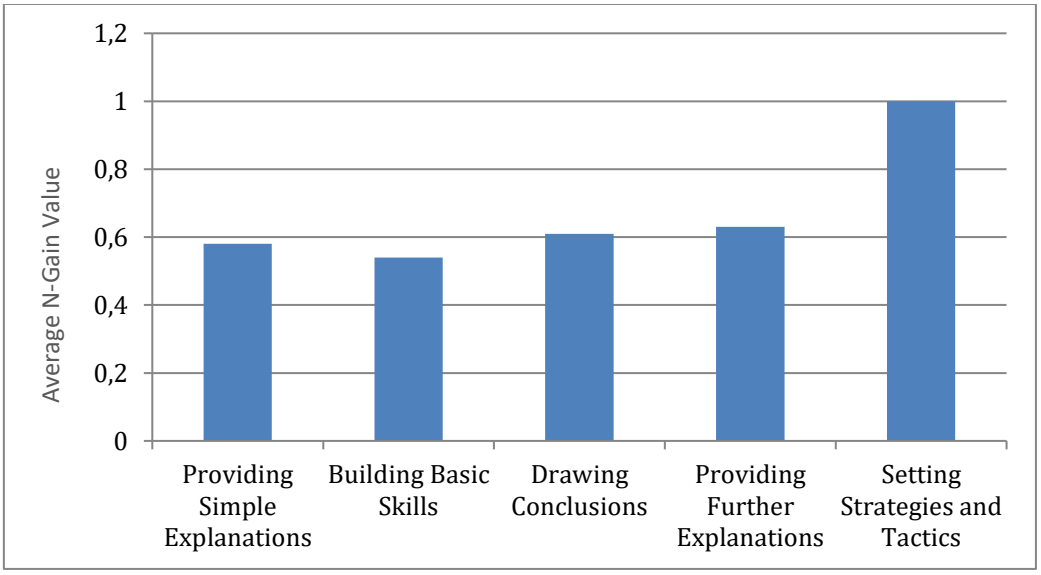

Figure 1. Critical thinking ability indicators.

Based on the data in Figure 1, indicators providing simple explanations, building basic skills, drawing conclusions, and providing further explanations are included in the "medium" category. Meanwhile, indicators for managing strategy and tactics are in the "high" category. The N- Gain value for each indicator is as follows: providing simple explanations (0.58), building basic skills (0.54), drawing conclusions (0.61), providing further explanations (0.63), and organizing strategies & tactics (1.00).

This finding is in line with research conducted by Fatikhatus & Tutut (2023), which shows that students' critical thinking abilities have increased on the indicators of providing simple explanations, building basic skills, drawing conclusions, providing further explanations, and organizing strategies and tactics [17]. Each indicator shows an increase in the categories “medium” and “high.” Based on these results, it can be concluded that the application of the PjBL model integrated with STEM is effective in improving students' critical thinking skills on various indicators.

The indicator providing a simple explanation has an N-Gain value of 0.58, which is included in the “medium” category. This shows an increase in critical thinking skills on this indicator. After implementing the PjBL model integrated with STEM, students experienced significant progress in critical thinking, especially in providing simple explanations, although the improvement was still in the moderate category [18]. In line with research conducted (Raula, 2021) that indicators providing simple explanations are still in the medium category because the level of thinking of junior high school students is a transition to a higher level of thinking. As an illustration, students' answers can be seen in Table 9.

Based on the Table 9 it appears that students have not been able to provide an appropriate explanation regarding the working mechanism of wind energy, especially in areas with low wind speeds. On the other hand, in the answers shown in second answer, students are able to explain the working principles of wind energy in generating electricity in areas with low wind speeds. According to research Suryana dkk (2021) critical thinking skills can arise and be trained through daily events and increasing practice questions [19].

Table 9. Illustration of students' answers.

Question	Answer 1	Answer 2
1. Wind energy is generated from a turbine that converts the kinetic energy of the wind into electrical energy. Based on the information in the reading, how can the working principle of a wind turbine be optimized to generate electricity in areas with low wind speeds?	Simply cover the turbine with glass.	1. Turbine Design: - Longer and wider blades capture wind more effectively. - Optimized angle for wind capture. - A number of 2-3 blades is more efficient than many blades. 2. Technology: - Automatic control system (optimizes wind production based on speed).

3.1. *Implementation of STEM (Science, Technology, Engineering and Mathematics) Integrated Project Based Learning Learning Model*

Learning with the STEM-integrated PjBL model takes place over two meetings. At the first meeting, the main focus was given to alternative energy materials, especially wind energy. Meanwhile, at the second meeting, students were directed to design and make a project in the form of a miniature windmill. The implementation of learning in this model is evaluated through an observation sheet filled in by the observer. The observation sheet records the learning stages carried out by teachers and students, in accordance with the steps in the STEM integrated PjBL model.

The observation process was carried out by two observers who marked the column "Yes" if a learning activity was carried out, and "No" if it was not carried out. The data obtained was then analyzed in percentage form, the results of which can be seen in Table 10.

Table 10. Percentage of implementation of student activities.

Session	Percentage of Implementation (%)	Criteria
1	100%	Very good
2	100%	Very good
Total	100%	Very good

Based on the percentages listed in Table 10, the implementation of learning using the STEM integrated PjBL model reached 100% at both meetings. Each stage in this learning is structured according to the STEM integrated PjBL syntax, which includes reflection, research, discovery, application, and communication [20].The first meeting of learning activities starts from the reflection stage, the teacher opens the lesson, provides apperception and explores the students' initial concepts to convey the learning objectives. Then students watch videos about the use of alternative energy, especially wind energy, and ask questions about the videos they observe. Then the students were divided into 3 groups and given LKPD for each group. In the LKPD there is a description of the underlying problems regarding alternative energy materials, especially wind energy. At the research stage, students look for information about how wind energy works, as well as examples of applications of wind energy-based technology from the video link included in the LKPD. Next, at the discovery and application stage, students fill in questions on the LKPD, there are two questions that require students to formulate problems and solutions regarding wind energy as a design material for making miniature windmills at the second meeting. After each group of students discusses, namely at the communication stage, the teacher asks the students to present the results of their discussion, especially on two questions regarding problem formulation and solutions regarding the use of wind energy. Activities ran smoothly and as expected. In the final stage the teacher provides a learning review so that students better understand the concept of using alternative energy, especially wind energy.

At the second meeting, students focused on designing and creating projects. In the reflection stage, the teacher provides apperception by providing material that has been studied in the previous meeting, such as "When you turn on the fan at home, the wind produced feels cool, what makes the fan spin? Do you think the wind produced can be used to produce electricity?" Then the teacher gives examples of

miniature windmill projects that have been made previously, students observe examples of miniature windmill projects. Then the students were divided into 3 groups, adjusted to the groups at the first meeting. Each group was given an LKPD which contained design, project creation and project trial results. At the Research and Discovery stage, students are asked to observe a video about how to make a miniature windmill using 3 different materials, then students answer the questions on the LKPD according to the information obtained from the video observations. At the project creation stage, namely the application stage, students choose different materials for each group.

Some use plastic propellers, ice cream sticks and cardboard. Learning activities at the second meeting went smoothly, until at the final stage of communication, students presented the results of their project creation. At the product assessment stage, there were 2 groups that carried out re-design. 2 groups of students innovated the miniature windmills they had made, by making the windmill look like a ship and making bent windmill blades, with the aim of making the resulting rotation fast.

After the learning activities are carried out, a posttest is carried out outside class hours on a different day. During the posttest students were able to answer questions correctly. In the learning process, students collaborate the knowledge they have with fellow group members to produce one-way actions or decisions [21]. Through group activities, students are able to express their abilities in working on their projects, their ability to understand concepts [22].

3.2. *Student Responses to the Project Based Learning Model integrated with STEM (Science, Technology, Engineering and Mathematics)*

In the final stage of the research, students were asked to fill out a questionnaire aimed at measuring their responses to the application of the STEM integrated PjBL model in learning alternative energy, especially wind energy. This questionnaire consists of 16 statements, which are divided into 8 positive statements and 8 negative statements. The distribution of questionnaires is carried out in the form of questionnaire sheets which are filled in directly by students. A complete list of statements contained in the questionnaire can be found in the attachment section

The average positive statement score reached 90.5%, which shows that students' responses are in the "very good" category. The results of this questionnaire indicate that students support the use of the STEM integrated PjBL model in learning. The highest score was obtained in question number 2, with a percentage of 92.5%, which stated that "Learning science using a project-based model is very interesting and not boring." This shows that students feel enthusiastic and not bored during the learning process. They are also more interested because this model allows them to explore tools and deepen their understanding throughout learning activities.

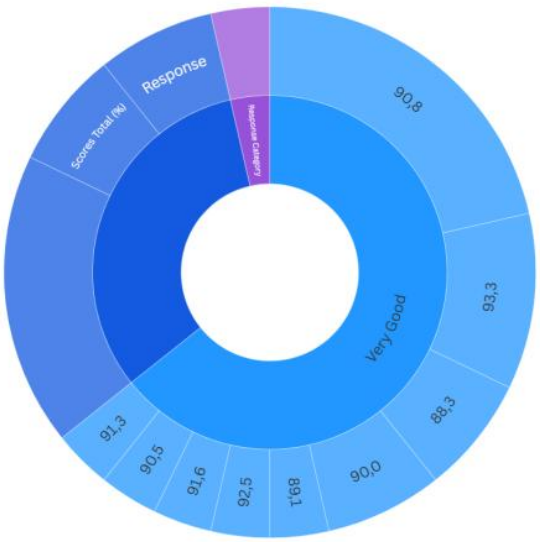

Figure 2. Student Response Values for Negative Statements

Based on Figure 2 for negative statements the Likert scale points are reversed, where strongly disagree is at the highest point, namely In contrast to positive statements, this aims to ensure that the final score remains in line with the positive statement, so that a larger value indicates a more positive response to the aspect being measured. The average score of students' responses to negative statements reached 91.3%, which is included in the "very good" category. The highest scores were obtained on questions number 9, 12, and 13, each with a score of 93.3% in the same category. In question number 9, the statement presented is, "With the project-based learning model, I feel less motivated to take science lessons." These results indicate that students actually feel motivated in learning with the STEM integrated PjBL model.

Meanwhile, in question number 12, the statement reads, "The project-based learning model does not provide encouragement for me to learn." The scores obtained indicate that students agree that this method actually encourages them to learn better.

Finally, item number 13 states, "I often feel bored learning using the project-based learning model." The results obtained show that students do not experience boredom and respond positively to the use of this model. Overall, these findings confirm that students have a very good response to the implementation of STEM integrated PjBL. In line with research (Setari, 2024) that students' attitudes are positive towards learning using the PjBL-STEM model. This happens because learning is centered on students, where they can design product designs according to their individual creativity. Apart from that, research (Selviana, 2024) on student response questionnaires shows a good reaction to the STEM integrated PjBL model, as evidenced by the percentage of student responses to each statement given, with an average of 90%.

4. Conclusion

Based on the findings of the research conducted, it can be concluded that the application of the integrated STEM (Science, Technology, Engineering and Mathematics) Project Based Learning learning model can improve students' critical thinking skills on alternative energy material on the topic of wind energy in junior high school. Increasing students' critical thinking skills after carrying out learning using the STEM (Science, Technology, Engineering and Mathematics) integrated Project Based Learning model obtained an N-Gain result of 0.6360 in the medium category. Which means it can be concluded that the application of the STEM (Science, Technology, Engineering and Mathematics) integrated Project Based Learning learning model can improve students' critical thinking abilities. Students' responses to the STEM (Science, Technology, Engineering and Mathematics) integrated Project Based Learning learning model resulted in a score of 90.5 with a very good category for positive statements and 91.3 with a very good category for negative statements. Based on the results of the discussion, the conclusion from learning using the Project Based Learning integrated STEM (Science, Technology, Engineering and Mathematics) learning model has a significant influence on students' critical thinking abilities.

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