



## IMPROVING STUDENTS' CRITICAL THINKING SKILLS THROUGH PROJECT-BASED LEARNING USING MINI SOLAR PANELS

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### Abstract

Physics learning that still uses the lecture method causes students to have limited critical thinking skills. Therefore, this study examines the feasibility of learning, the improvement of critical thinking skills, and students' responses to the implementation of the Project Based Learning (PjBL) model of mini solar panels on renewable energy material. This research design uses a pre-test post-test of one group tested on three classes as a replication. The implementation of the PjBL learning model of mini solar panels with the observed aspects on average for the three classes is 99.17%. The increase in students' critical thinking skills shows a score of class X-H from 61.18 to 85.99; class X-F from 58.39 to 83.50; class X-D from 62.78 to 87.72. The average percentage of student questionnaire responses for the three classes is 94.52%, which is included in the Very Good category. Data analysis using normality test and produced normally distributed data, then continued with paired t-test in all three classes to test the hypothesis with results  $<0.05$ , so the initial hypothesis was rejected and showed significant differences in all three classes. N Gain analysis of the pre-test post-test results in all three classes showed a moderate category with an average of 0.698 for all three classes. From this research data, the application of the mini solar panel project-based learning model successfully improved critical thinking skills.

**Keywords:** Project based Learning, critical thinking, mini solar panel

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## INTRODUCTION

According to Ministry of Primary and Secondary Education (2025), the goal of learning physics includes developing critical thinking skills by applying physics understanding in everyday life. Critical thinking is one of the 21st-century skills that students need, and it is emphasized as a competency that must be given in the learning process in today's globalized era to help students face future challenges (Rafiah & Huriaty, 2021). Critical thinking skills are believed to play a major role in students' success during their education, in their careers, and in other social life contexts (Birjandi & Bagherkazemi, 2010). This is because thinking critically is one of the skills students need to face future challenges. Considering the urgency and importance of critical thinking, the author agrees that critical thinking is a very fundamental skill that should be fully encouraged in today's educational environment. This is recognizing that education plays a crucial role in producing outcomes that can help students develop critical thinking skills.

The research data from Susilawati et al., (2020) was obtained by giving students a critical thinking skills test. The data analysis technique used was a type of quantitative descriptive model. Students' critical thinking skills were measured using essay questions. The questions were developed based on critical thinking skill indicators developed by Ennis (2013). The indicators that were identified and measured include: questioning, proposing hypotheses, making decisions, considering the use of appropriate procedures, recording observation results, interpreting questions, identifying and handling irrelevance, and providing definitions. The results showed that 21% of students had moderate critical thinking skills, 64% were in the low category, and 15% were in the very low category. No students had high or very high critical thinking skills. This can happen because the physics learning often encountered in schools is physics learning using direct learning and lecture models (Susilawati et al., 2020).

According to Susilawati et al. (2020), the indicators of critical thinking skills that were measured include eight indicators: identifying questions, making hypotheses, determining actions, considering the use of appropriate procedures, recording observation results, interpreting questions, identifying and handling irrelevant things, and providing definitions. The analysis results showed that five indicators fell into the low category and three indicators were in the medium category. In line with the preliminary study conducted by the researcher at SMA N 2 Tuban with 10th-grade students by giving them

critical thinking questions consisting of 5 indicators according to (Ennis, 1985), namely giving simple explanations, building basic skills, drawing conclusions, providing further explanations, and developing strategies and tactics. Students answered correctly for the indicator of giving simple explanations at 62.5%, building basic skills at 52.5%, drawing conclusions at 52.75%, providing further explanations at 55.5%, and developing strategies and tactics at 43.75%. Based on this analysis, students' critical thinking skills are categorized as low, with scores ranging from 43.75% to 62.5%.

Project Based Learning (PjBL) is an active learning model that connects technology with everyday life situations through the implementation of projects that produce concrete products. The PjBL model encourages students to independently engage in improving their thinking skills (Kholida, 2020). This PjBL learning model integrates technology with everyday life contexts through projects that result in real products (Riza, 2020). Project-based learning can boost student motivation (Handayani, 2020). Project-based learning has several phases and steps.

Project-based learning involves students in real-world problem situations, which allows them to gain a deep understanding and manage their own projects as part of the learning process (Trianto, 2014). The project-based learning model can engage students and make them aware that as students, they need to have critical thinking skills and be able to do their work well both individually and in groups. According to Hosnan (2014), project-based learning has great potential to create engaging and meaningful learning experiences for students. According to Hartono and Asiyah (2018), project-based learning has several advantages, such as motivating students to learn by working on projects, boosting students' creativity and problem-solving skills, improving teamwork, creating a fun atmosphere, and encouraging the development of scientific attitudes, including accuracy, integrity, responsibility, and innovation.

According to research conducted by Insyasiska (2015), the use of a project-based learning model can improve students' thinking skills through contextual project learning. Students' cognitive skills increase compared to learning that does not involve projects. In research conducted by Oktavianto (2017), it was stated that project-based learning is effective in improving critical thinking skills. This happens because students are challenged to solve problems, they become active in their learning, student participation in project implementation is more organized, students have the freedom to carry out projects, and students are motivated to compete for the best project. After

using the PjBL learning model, students' critical thinking skills increase compared to before. These findings are consistent with the research conducted by Permata et al. (2019), which showed that project-based learning models can develop and enhance students' critical thinking skills. For example, in the planning stage, students are trained to make decisions. During the implementation stage, students are asked to analyze experiments based on the theory underlying the project, so the critical thinking indicator that emerges is argument analysis. Meanwhile, in the evaluation stage, critical thinking skills are demonstrated through decision making and evaluation.

According to Dikdasmen (2025), the main curriculum in use is the Merdeka curriculum, which emphasizes Project Based Learning (PjBL) as the core method. PjBL in high school physics learning is defined by Dikdasmen as a learning process where students engage in authentic projects that connect physics theory with practical problems. Quasi-experimental studies in high schools (fluids, energy) show that PjBL produces higher post-test scores and N-gain compared to direct/conventional learning, both in cognitive aspects and science process skills (Zalenti, 2025).

Energy is one of the important factors for achieving sustainable development (Khan et al., 2020). The world's energy sources have changed several times, from initially mostly using biomass like firewood to meet energy needs, to fossil fuels like coal, oil, and natural gas, triggered by the industrial revolution in the 1900s. The increasing use of fossil energy has caused a rise in greenhouse gas emissions, making the climate unstable and increasing the Earth's temperature and sea levels (Pertamina, 2020).

Renewable energy is an energy source that comes from continuous natural processes and can be replenished in a relatively short time, unlike fossil energy sources which are limited and produce negative environmental impacts like greenhouse gas emissions and air pollution (Chen et al., 2020). Solar energy is one type of renewable energy with huge potential because of the abundant sunlight that is widely available in many areas, including Indonesia. Solar energy can be converted into electricity through photovoltaic technology, commonly known as solar panels. By using solar panels, sunlight can be directly transformed into clean and sustainable electric current, and it plays an important role in supporting the Sustainable Development Goals (SDGs) and climate change mitigation (Dwisari et al., 2023).

The development of power generation systems using energy sources other than fuel is necessary to support the electricity needs of the community. Solar power generation systems

(PLTS) are one solution to address this issue. Using solar energy falls into the category of renewable energy, is environmentally friendly, and does not cause pollution (Indartono, 2008). Tropical regions like Indonesia have great potential to convert sunlight into electricity due to the country's geographical location on the equator, which allows it to receive consistent sunlight throughout the year. Mini solar panel projects are one way to implement project-based learning (PjBL) in the context of education about renewable energy. Through this activity, students not only learn the theory of solar energy but also get directly involved in assembling or utilizing solar panels in a simple form as a learning aid. This approach encourages students to be actively involved in learning, so their critical thinking and problem-solving skills can be sharpened better. It should be noted that the limitations of this research are that it only uses three classes as replication and renewable energy materials using mini solar panels.

## METHOD

This study uses a pre-experimental design with a one-group pre-test post-test design. Through this design, three classes as replication classes of this research treatment considering the very large number of classes at the research location. The procedure involves giving a pre-test before the treatment (Project Based Learning model) outside of class time in the first meeting, followed by a post-test outside of class time after the second meeting using the same questions. With this design, there are three classes used as replications for implementing the project-based learning model in a mini solar panel project.

This study looks at several types of variables that help in carrying out and analyzing data systematically. The control variables in this study are the teacher's teaching skills and renewable energy materials, while the manipulated variable here is the Project-Based Learning model with one of the mini projects being a 'mini solar panel.' The response variables in this study are the implementation and the results of improving students' critical thinking skills.

## Research Design

This research used a pre-experimental approach with a single-group pre-test post-test design. This design used three classes as replication classes with the same treatment. The sample was determined using purposive sampling. Purposive sampling is a non-probability method in which researchers select samples based on their objectives and knowledge of the population. The samples were determined by the researcher: classes X-C, X-D, and X-E, in coordination with physics teachers at

SMA N 2 Tuban. The sample consisted of 36 students from each class, respectively. The procedure involved administering a pre-test before the treatment (Project-Based Learning model) outside of regular class hours at the first meeting, followed by a post-test outside of class hours after the second meeting, using the same questions. The formulation of this implementation design is as follows.

**Table 1.** Data collection techniques table

Class	Pre test	Treatment	Post test
X - D	O <sub>1</sub>	X	O <sub>2</sub>
X - F	O <sub>1</sub>	X	O <sub>2</sub>
X - H	O <sub>1</sub>	X	O <sub>2</sub>

There are 6 questions presented to measure students' critical thinking skills in renewable energy physics for grade 10 high school students. Each question contains 1 indicator of critical thinking skills used by the author, namely the indicators according to Facione (1985), namely Interpretation, analysis, evaluation, inference, and explanation. By giving students' critical thinking skills tests, the results of learning analysis on the knowledge aspect are obtained. The test consists of a pre-test given before learning with the Project Based Learning (PjBL) model for the solar panel mini project.

One of the critical thinking skill indicator questions given (analysis):

1. Rendy and Rafi built a miniature solar power plant as part of a concrete step towards using alternative energy. They used 3  $\Omega$  solar panels. After the entire solar power plant assembly was completed, Rendy and Rafi tested the device by heating the solar panels for varying amounts of time. They found that the longer the heating time, the greater the power generated. They wanted to increase the power generated by the solar panels, so Rendy suggested increasing the surface area of the solar panels. Rafi believed that increasing the heating time was more effective than purchasing more solar panels, as radiation power increases with increasing temperature. Analyze which of Rendy and Rafi's ideas best fits the concept you have learned!

From one of the example questions, it is clear that the instrument provided to measure critical thinking skills has been validated by two expert lecturers from physics at Unesa and one physics teacher at SMAN 2 Tuban.

### Research Objective

Instruments are data collection tools in research that aim to make it easier for researchers

to gather and process data. In this study, the instruments used are:

1. Lesson Implementation Observation Sheet  
Observations are carried out through direct monitoring of the learning process. These observations are recorded by three observers on an observation sheet that uses a research scale, aiming to assess the extent to which the learning has been implemented.
2. Pre-test and Post-test questions based on critical thinking skills indicators  
The pre-test and post-test questions serve as tools to measure students' learning outcomes, applied under pre-treatment (pre-test) and post-treatment (post-test) conditions in the implementation of the critical thinking skills model.
3. Student Response Questionnaire  
The response questionnaire in this study contains questions related to aspects of motivation and satisfaction after learning about the application of the Project Based Learning model through the "mini solar panel" project.

### Data Collection Technique

The data collection techniques used include:

1. Observations  
Observation was done by directly watching the learning process. This observation was noted by three observers on an observation sheet using a research scale, aimed at assessing how well the learning was carried out. The sheet included items that evaluated how well the learning matched the Project Based Learning model and the application of material found in the teaching module. Filling out the observation sheet was done by the observers checking ( $\surd$ ) according to the assessment criteria in the available columns.
2. Tests (pre-test & post-test)  
treatment (pre-test) and post-treatment (post-test) conditions in the implementation of the critical thinking skills model. The written test instruments are designed with appropriate cognitive levels to assess how much learning outcomes improve after the intervention on renewable energy materials.
3. Student Response Questionnaire  
The student questionnaire was distributed at the end of the second session of learning through Google Forms. The response questionnaire in this study contains questions related to aspects of motivation and satisfaction after learning about the implementation of the Project Based Learning model through the 'mini solar panel' project. There are 36 statements in the response questionnaire that students will answer by choosing an option in the available column and

filling in the answer column for reflection, feedback, and suggestions.

**Data Analysis Technique**

The data analysis techniques applied in this study include:

1. Analysis of Learning Implementation Observations

The observation sheet data was analyzed using an average analysis, calculated by dividing the total score by the maximum score and then multiplying the result by 100%. The total score is the sum of all scores obtained from all observers, and the maximum score is the highest score multiplied by the number of questions multiplied by the number of respondents. The results of this calculation can be categorized using the following criteria.

**Table 2.** Criteria for learning implementation score percentage

Percentage	Criteria
81%-100%	Very Good
61%-80%	Good
41%-60%	Enough
21%-40%	Less
0%-20%	very lacking

2. Analysis of Improving Critical Thinking Skill Knowledge test data (pre-test and post-test) will be processed to draw conclusions through hypothesis testing, which includes data normality tests, paired sample t-tests, and Normalized Gain<g>

A. Prerequisite Test

1) Normality Test

Data normality test is a test of the normality of data distribution to determine the percentage of how normal the data is in the dependent variable (critical thinking skills results) and independent variable (Project Based Learning model through the 'mini solar panel' project). Based on literature review, the Shapiro-Wilk test is the right model to check the normal distribution of data with a sample size of less than 50. The criteria for normality are that the data has a normal distribution (significance value > 0.05) and non-normal distribution (significance value < 0.05) (Difinubun, 2023).

2) Paired Sample T-Test

This test is used to compare the average scores of two paired measurements (done on the same subjects) to determine whether there is a significant difference.

The test has specific assumptions that must be met. The hypothesis is H<sub>0</sub> (p-value > 0.05) that there is no significant difference between pre-test and post-test scores. H<sub>1</sub> (p-value ≤ 0.05) indicates a significant difference showing a positive effect from the method used, so H<sub>1</sub> is accepted (Maria et al., 2025).

3) Normalized Gain <g>

The increase in students' learning outcomes after participating in learning activities using instruments with the mini solar panel project PjBL learning model can be seen through the normalized gain test with the following equation.

$$<g> = \frac{\% \text{ skor posttest} - \% \text{ skor pretest}}{100\% - \% \text{ skor pretest}}$$

Gain scores can be identified based on the criteria for gain score improvement as stated by Hake as follows.

**Table 3.** N-Gain score classification

Limits	Category
(<g>) ≥ 0.7	High
0.8 > (<g>) ≥ 0.3	Currently
(<g>) < 0.3	Low

3. Student response questionnaires

Student response questionnaires were analyzed using the Guttman scale, which is designed to measure data with straightforward 'Yes' or 'No' answer choices. The Guttman scale table has 2 answer criteria.

**Table 4.** Guttman scale

Answer	Score
Yes	1
No	0

The percentage results are calculated by dividing the number of "Yes" answers from respondents by the total number of respondents, then multiplying by 100%. The results can be categorized using the following criteria.

**Table 5.** Survey response score percentage criteria

Percentage	Criteria
81%-100%	Very Positive
61%-80%	Positive
41%-60%	Fair
21%-40%	Less
0%-20%	Not Positive

**RESULTS AND DISCUSSION**

The results of the study were obtained from several data collection processes by conducting

three learning meetings at school. The research was conducted at the last three meetings of the material with the condition that students had received teaching from school teachers regarding the material of effort, energy and simple machines using two classes as samples, namely class X-H, X-F and X-D located at SMA Negeri 2 Tuban. The replication classes, which are classes X-D, X-F, and X-H, were given the treatment of a project-based learning model using a mini solar panel to improve students' critical thinking skills. In the learning process for these three classes, of course, there were controlled variables such as the teacher's teaching skills and renewable energy materials. This was done to minimize the influence of other factors that could affect the research results.

The learning outcomes in this study show differences among the three classes, but all three classes showed improvement. The implementation of learning in class X - H showed very good results. The average overall aspect of learning implementation in the first meeting had a reliability of 98.75%. The implementation of learning in class X - F also showed very good results. The average overall aspect of learning implementation in the first meeting had a reliability of 98.75%. The implementation of learning in class X - D showed very good results as well. The average overall aspect of learning implementation in the first meeting had a reliability of 100%.

The average pre-test scores for class X-D were 62.78, X-F 58.39, and X-H 61.18, while the average post-test scores were X-D 87.72, X-F 83.50, and X-H 85.99. From these results, it can be stated that using the Project Based Learning model with a mini solar panel project to improve students' critical thinking skills led to an increase in their critical thinking scores from the pre-test to the post-test.

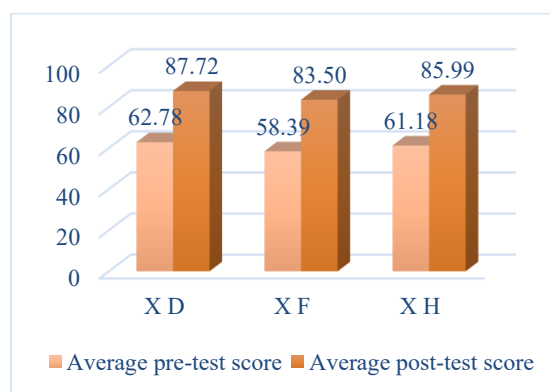
Based on the results of the pre-test and post-test of class X-H, it was found that students' test scores increased after learning with the mini solar panel PjBL model. The students' N-Gain improvement was in the medium category, with an average increase of 0.692. Based on the results of the pre-test and post-test for class X-F, it was found that students' test scores improved after receiving lessons using the mini solar panel PjBL model. The students' N-Gain test improvement was in the medium category with an average increase of 0.687. Based on the results of the pre-test and post-test for class X-D, it was found that the students' test scores increased after receiving lessons with the mini solar panel PjBL model. The students' N-Gain test improvement was in the medium category, with an average increase of 0.698.

Based on the data in the table, it can be seen that the test results of students' thinking in all classes are normally distributed because they have a sig. value  $< 0.05$ .

Based on the table, it can be seen that in class X-H, Sig. (2-tailed) is 0.000, which is less than 0.05, so it can be concluded that  $H_0$  is rejected. This means there is a difference in students' learning outcomes between the pre-test and post-test, so it can be said that the implementation of the mini solar panel project-based learning model has an effect on improving the critical thinking skills of class X-H students.

Based on the table, it can be seen that in class X-F, Sig. (2-tailed) is 0.000, which is less than 0.05, so it can be concluded that  $H_0$  is rejected. This means there is a difference in students' learning outcomes between the pre-test and post-test, so it can be said that the implementation of the mini solar panel project-based learning model has an effect on improving the critical thinking skills of class X-F students.

Based on the table, it can be seen that in class X-D, Sig. (2-tailed) is 0.000, which is less than 0.05, so it can be concluded that  $H_0$  is rejected. This means there is a difference in students' learning outcomes between the pre-test and post-test, so it can be said that the implementation of the mini solar panel project-based learning model has an effect on improving the critical thinking skills of class X-D students.



**Figure 1.** Average pretest and posttest scores

The implementation of the Project Based Learning (PjBL) model assisted by mini solar panels on renewable energy material received a percentage of 94.57% in class X-D, 95.14% in class X-E, and 93.86% in class X-F. The average positive response percentage from the three classes is 94.52%, which falls into the Very Good category. This shows that most students gave a positive response to the learning applied. Students felt more motivated, active in learning, found it easier to understand renewable energy concepts, and were

more enthusiastic in participating in mini solar panel project activities.

**Table 6.** Normality test for pre-test and post-test data

Class	Kolmogorov-Smirnov <sup>a</sup>			Shapiro-Wilk			
	Statistic	df	Sig.	Statistic	df	Sig.	
Result	1	.122	35	.200*	.976	35	.626
	2	.061	35	.200*	.979	35	.734
	3	.137	35	.095	.949	35	.108
	4	.083	35	.200*	.968	35	.384
	5	.122	35	.200*	.976	35	.626
	6	.079	35	.200*	.976	35	.634

This is a lower bound of the true significance.

a. Lilliefors Significance Correction

**Table 7.** Paired samples test class X-H

		Paired Differences			95% Confidence Interval of the Difference	t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean					
Pair 1	Pretest X-H - Posttest	-19.779	6.823	1.153	Lower: -22.123 Upper: -17.436	-17.151	34	.000
Pair 2	Pretest X-F - Posttest	-21.860	11.855	2.004	Lower: -25.932 Upper: -17.788	-10.909	34	.000
Pair 3	Pretest X-D - Posttest	-20.358	6.621	1.119	Lower: -22.632 Upper: -18.084	-18.190	34	.000

## CONCLUSION AND SUGGESTION

### Conclusion

The learning outcomes in this study show differences among the three classes, but all three classes showed improvement. The implementation of learning in class X - H showed very good results. The average overall aspect of learning implementation in the first meeting had a reliability of 98.75%. The implementation of learning in class X - F also showed very good results. The average overall aspect of learning implementation in the first meeting had a reliability of 98.75%. The implementation of learning in class X - D showed very good results as well. The average overall aspect of learning implementation in the first meeting had a reliability of 100%.

Based on the N-gain analysis, there was a consistent increase in critical thinking results at a moderate level across the three classes. The inferential analysis results showed that the normality test in the three classes for the pre-test and post-test results were normally distributed, then continued with paired t-tests replicated across the three classes, with the conclusion that there was a significant difference before and after implementing the mini solar panel project-based learning model to improve students' critical thinking skills. The average positive response percentage from the three classes is 94.52%, which falls into the very good category.

### Suggestion

The research results show that applying the project-based learning model to improve critical thinking skills can be implemented more widely in other physics learning materials by involving more schools from various backgrounds to measure its overall effectiveness.

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