Jurnal Penelitian Pembelajaran Fisika
Vol. 16 Issue 1 – January 2025, p120-129
p-ISSN 2086-2407, e-ISSN 2549-886X
Available Online at http://journal2.upgris.ac.id/index.php/JP2F
DOI: 10.26877/jp2f.v16i1.1398

The Effect of Project Based Learning Model on Science Understanding and Process Skills of Renewable Energy Material

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Received: 12 December 2025. Accepted: 15 January 2025. Published: 31 January 2025.

Abstract. In the Merdeka Curriculum, learning objectives include learning skills that students must achieve at each stage. The learning objectives in Phase E consist of elements of scientific understanding and process skills. This study aims to analyze the effect of the Project-Based Learning (PjBL) model on scientific understanding and process skills in renewable energy topics for 10th-grade students. The research employed a quasi-experimental method with a pretest-posttest non-equivalent control group design. The research instruments included multiple-choice tests to measure scientific understanding and observation sheets to assess process skills. The findings showed that the average posttest score of the experimental class was higher than that of the control class, and the Independent Samples t-test revealed a significant difference in scientific understanding. Students' process skills also showed significant improvement. The results indicate that students in the experimental class demonstrated better improvements in scientific understanding and process skills compared to those in the control class. In conclusion, the implementation of PjBL effectively enhances scientific understanding and process skills through an active and real-world problem-based learning approach.

Keywords: project based learning, scientific understanding, process skills

1. Introduction

Physics is a branch of natural science that studies objects in nature that have a connection with everyday human life, and is a science that essentially contains knowledge, ways of thinking and the process of investigation. In the world of physics education examines every phenomenon with a variety of scientific methods that must be based on scientific attitudes and results in the form of theories, concepts and universal laws. Learning physics also requires special methods because it cannot be separated from mastering concepts that can be applied in solving physics problems [1]. Learning in the independent curriculum takes into account student development and skills that are tailored to student learning needs so that learning is more meaningful and enjoyable. The independent curriculum consists of a program in the form of a project to strengthen Pancasila students using a project-based learning approach, this approach is used to observe real problems. The purpose of implementing the project to strengthen the profile of Pancasila students is to provide learning experiences that are flexible, interactive and make students actively involved directly with the surrounding environment.

There are 6 profiles of Pancasila students who are the focus in fostering student character education, namely (1) noble character, (2) critical reasoning, (3) creativity, (4) global diversity, (5) independence, (6) mutual cooperation [2]. The implementation of an independent curriculum is designed to fulfill education along with digital and technological advances, the implementation of an independent curriculum students are given the freedom to choose a way of learning that suits their style and needs. Students are also encouraged to develop creative and critical thinking skills, with the hope that students will be able to solve complex and real problems. With the independent curriculum, students not only excel in academics, but also have character and skills that are useful in the future [3]. Teachers can plan learning strategies that are effectively applied in teaching and learning activities, one way that can be used is to give students a project or task that will require students to solve a particular physics problem. Students are made to learn in groups in planning the appropriate physics principles and concepts, students will learn the appropriate material then applied to problems in a more real context.

Known as project-based learning, this learning model will emphasize problem solving, cooperation, and active involvement of each student in the learning process [4]. This model is believed to make students build their own understanding by grasping existing concepts and broadening their view of the concept [5]. Teachers should pay attention to the characteristics in creating and adjusting projects in achieving project-based learning standards, where teachers must know the academic standards and abilities that will be achieved by students through the completion of the project, besides that teachers are expected to know that the project objectives are achieved through active exploration, students will apply information or knowledge in dealing with problems related to the real world, students' exploration will vary and not only refer to one answer, and students present the learning outcomes of the project through simulation presentations and so on [6].

The structure of the independent curriculum consists of intracurricular and co-curricular activities, which can also be complemented by extracurricular activities. In intracurricular competencies are formulated in the form of learning outcomes, namely competencies that students must achieve within a set time span in the form of phases or stages of student learning development (phases A to F), not per year. In co-curricular competencies are formulated in the form of project dimensions to strengthen the profile of Pancasila students, student participation in extracurricular activities is voluntary, the aim is to develop talents and interests outside the realm of academic learning [7]. The use of learning models in the teaching and learning process is expected to increase the effectiveness and efficiency of learning in achieving learning objectives, through this learning model it will allow teachers and students to focus on the material, and the delivery of material will be easier for the teacher to convey. This learning model is very helpful for teachers in managing the class during the learning process, in order to create an effective and conducive learning environment [8].

The implementation of the learning model is used to increase student activeness and then will help students understand the material presented easily, the learning process is required to run interactively, inspiring, fun and can provide motivation for students to actively participate and develop creativity in accordance with talents and interests, and student development [9]. A strategic approach is one way to overcome student boredom because they are actively involved in learning, learning is not only about mastering the theoretical concepts of certain subjects, but must be able to provide interesting and meaningful experiences [10].

Project-based learning is a learning model that in its first step uses projects in acquiring knowledge and is integrated based on direct experience from real life, this learning model is used for complex problems that students investigate and understand [11]. This learning model emphasizes active, collaborative learning and student involvement in solving problems that are real and relevant to the subject matter [12]. PjBL is a learning approach that focuses on exploring natural knowledge, understanding natural concepts and mechanisms, this learning involves various disciplines and direct application in the field, the process begins with asking fundamental questions or identifying a problem, which then ends with making a product (project) as a solution whose results can be concluded [13]. PjBL is a model based on constructivism and accommodates students' active involvement in learning for contextual problem solving, through PjBL students will realize real-world problems not just solving problems using certain appropriate equations [14].

Students will learn to build a problem framework, observe, collect data, organize problems, compile facts, analyze data, and compile arguments to obtain information and develop science concepts in problem solving, both individually and in groups [15]. Constructivism is a learning theory that emphasizes students to be able to build their own understanding through experience and a student-centered teaching process [16]. In its implementation, students will be involved in several projects that are relevant to the material to be delivered, besides that students are also involved in learning attitudes, knowledge, and skills [17]. Through PjBL students require analysis, evaluation and creation processes. Students will also be trained to develop skills in problem solving and decision making [10]. In addition, students will be encouraged to collaborate with peers which will make students communicate more effectively, with this students will understand concepts in depth which is essential in the world of education and everyday life [18].

The results of observations and interviews with physics subject teachers at SMAN 3 Bengkulu Tengah show that the learning that takes place so far has not fully implemented differentiated learning. Differentiated learning is a learning system that pays attention to the diversity of students including readiness, interests, learning styles, and needs of the students [19]. In the classroom learning process sometimes still applies lectures and question and answer, the learning process sometimes still applies teacher centered or teacher centered learning, besides that SMAN 3 Bengkulu Tengah only implemented the independent curriculum in July 2023. It is also known that students are more happy and interested in learning that is not only fixated on theory but also practice, students are more enthusiastic if learning is done in groups, based on the results of interviews conducted with teachers it was found that in the 2022/2023 school year students only made one project, namely on global warming material. Based on the description above, it is necessary to conduct research to find out how the effect of the project-based learning model will be implemented on renewable energy material for class X students. This study aims to determine the effect of project-based learning model on science understanding and student process skills on renewable energy material for class X SMAN 3 Bengkulu Tengah.

2. Method

This study employs a quantitative experimental approach using a quasi-experimental research design. The specific design applied is the pretest-posttest non-equivalent control group design. The quasi-experimental method is research that compares the effects between groups receiving treatment and other groups and measures the magnitude of the impact of the applied treatment. In this design, the experimental and control groups share similar characteristics as the samples are randomly selected from a homogeneous population. O_1 and O_3 represent the pretests (initial tests) for the experimental and control groups, respectively. Subsequently, a treatment (X) is given only to the experimental group in the form of project-based learning, while the control group receives direct instruction through the problem-based learning model. Following this, O_2 and O_4 are the posttests (final tests) for the experimental and control groups. The details of the non-equivalent control group design are presented in Table 1.

Table 1. Nonequivalent control group design.

Group	Pretest	Treatment	Postest
Experiment	O_1	X	O_2
Control	O_3		O_4

The research was conducted at SMA Negeri 3 Bengkulu Tengah from July to November 2024. The population consisted of 10th-grade students of SMA Negeri 3 Bengkulu Tengah for the 2024/2025 academic year, comprising 11 study groups. The sampling technique used was purposive sampling, selected based on specific considerations after conducting a population homogeneity test [20]. The are two classes selected as samples, each consisting of 33 students, the first class was made the experimental class while the second class was made the control class.

The study involved a learning outcome test as a data collection instrument to measure students' understanding of science before and after the treatment. The test consisted of 20 multiple-choice questions with varying levels of difficulty, which had undergone a validity test and were declared valid for measuring students understanding of science. Additionally, an observation sheet was used to assess students' process skills during the learning activities. The data collected focused on observing the fulfillment of the process skill indicators during the learning process. The observation sheet for process skills was measured using a Likert scale, categorizing the assessments into three levels: good, sufficient, and insufficient. Prior to use, the instruments were validated by three experts, including university lecturers and physics teachers. The data collected was analyzed for assumption and hypothesis testing using IBM SPSS Statistics 27 for Windows.

The data analysis techniques used in this study include descriptive statistical analysis, inferential statistical analysis, and hypothesis testing. Descriptive statistical analysis aims to describe the effects of the project-based learning model on students' understanding of science and skills in the renewable energy topic for 10th-grade students at SMAN 3 Bengkulu Tengah. For the science understanding instrument, tests for validity, reliability, difficulty level, and discriminating power were conducted. The item validity test was performed using SPSS Statistics 27 for Windows. The validity of an item was determined by comparing the value of r_{pbis} with r_{tabel}, if $r_{pbis} < r_{tabel}$, the item was deemed invalid, and vice versa. To test the validity of each multiple-choice item or dichotomous score (1 & 0), the point-biserial correlation was used, applying the equation presented in Equation 1 [21].

$$r_{pbis} = \frac{M_p - M_t}{SDt}\sqrt{\frac{p}{q}} \tag{1}$$

The process skills observation sheet underwent construct validity and content validity testing. For construct validity, expert judgment was sought to assess the extent to which the observation sheet reflects the aspects or indicators of process skills intended to be measured. These indicators include observing, questioning and predicting, planning and conducting investigations, processing and analyzing data and information, creating, evaluating and reflecting, and communicating results. Content validity testing was conducted to evaluate whether the items in the instrument comprehensively cover all aspects of the process skills being measured. This process involved three experts whose expertise aligns with the scope of the study. The Likert scale analysis used for evaluating the observation sheet is presented in Table 2.

Table 2. Likert scale for observation sheet.

Scor	Category
1	Good
2	Sufficient
3	Insufficient

Calculate the score obtained by each group for each indicator by determining the percentage using Equation 2.

$$Percentage\ (\%) = \frac{Scor\ obtained}{Maximum\ scor} \times 100\% \tag{2}$$

Inferential statistical analysis involved a normality test to determine whether the data follows a normal distribution using the Kolmogorov-Smirnov formula. The decision rule for this test is based on the significance level, where if the significance level is > 0.05, the data distribution is considered normal, and if the significance level is < 0.05, the data distribution is considered non-normal. The normality test is conducted using the following equation 3.

$$D = maksimum\ |F_0(X) - S_N(X)| \tag{3}$$

Next, a homogeneity test was conducted to determine whether two or more sample groups come from populations with the same variance. The homogeneity test was performed using Levene's test with IBM SPSS Statistics 27 for Windows. Interpretation of Levene's test: If the Levene statistic value > 0.05, it is concluded that the data variations are homogeneous. If the Levene statistic value < 0.05, it is concluded that the data variations are not homogeneous. The manual calculation of the homogeneity test can be done using an F-test, as shown in the following equation 4.

$$F = \frac{Larges\ variance}{Smallest\ variance} \tag{4}$$

If the data is normally distributed and homogeneous, hypothesis testing uses parametric statistical tests. The series of parametric tests performed in this study have a significance level of 5%. Hypothesis testing is conducted using a t-test, and the decision rule is: if the significance value is < 0.05 then H_0 is rejected and H_a is accepted. If the significance value is > 0.05, then > 0.05 maka H_0 is accepted and H_a is rejected. The pooled variance t-test is calculated using Equation 5.

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{(n_1-1)S_1{}^2+(n_2-1)S_2{}^2}{n_{1+}n_2-2}\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}} \tag{5}$$

3. Result and Discussion

This study aims to determine the effect of Project-Based Learning (PjBL) on students' understanding of science and process skills, specifically in the context of renewable energy topics for 10th-grade students at SMAN 3 Bengkulu Tengah. The data collected consists of pretest and posttest results for science understanding, using multiple-choice questions where each question has five answer options, with one correct answer and four incorrect answers. The final data analysis is conducted to test the first hypothesis proposed in this study. Descriptive statistical analysis of students' learning outcomes in the aspect of science understanding is presented in Table 3.

Table 3. Descriptive statistical analysis.

	N	Minimum	Maximum	Mean	Std. Deviation
Pretest Experimental Class	33	33	54	45.03	5.64
Postest Experimental Class	33	74	89	80.94	3.87
Pretest Control Class	33	36	60	50.76	6.20
Postest Control Class	33	67	84	75.36	3.86
Valid N (listwise)	33				

Based on descriptive analysis using IBM SPSS Statistics 27, the analysed statistics included N (number of data points), minimum value, maximum value, mean, and standard deviation. The implementation of the PJBL model in the experimental class showed a significant improvement in students' scientific understanding compared to the control class. The initial abilities of the students in the experimental class were relatively low before the treatment, with a moderate score distribution. After implementing PJBL, the posttest scores in the experimental class increased, indicating a positive impact on students' scientific understanding. Additionally, the score distribution became more uniform compared to the pretest. This improvement demonstrates the effectiveness of the PJBL model in helping students achieve a deeper understanding of scientific concepts. In contrast, the pretest scores of the control class were higher than those of the experimental class and exhibited a wider score distribution. Although the control class's posttest scores increased after traditional teaching, the average scores remained lower than those of the experimental class, with consistent score distribution.

The normality test using the Kolmogorov-Smirnov test showed the significance (Sig.) values for the pretest of the experimental class as 0.20, posttest of the experimental class as 0.71, and both the pretest and posttest of the control class as 0.20. Since the significance values for all data are > 0.05, it can be concluded that the data in this study follows a normal distribution. Additionally, a homogeneity test was performed to determine whether the data is homogeneous (the same) or heterogeneous (different). The significance (Sig.) Based on Mean was found to be 0.89 > 0.05, indicating that the variances of the posttest data for both the experimental and control classes are the same or homogeneous. While this is not an absolute requirement for the Independent Sample t-Test, it was conducted to check if the variances of the posttest data for the experimental and control classes are homogeneous. Since the data is normally distributed and homogeneous, parametric statistics can be used, specifically the Independent

Sample t-Test, also known as a test of differences. This test is used because the data obtained in this study comes from different subjects, as the study formed two groups: the experimental and control classes. The purpose of this test is to compare the means of two independent sample groups using IBM SPSS Statistics 27 for Windows. The results of the Independent Sample t-Test for students' science understanding are presented in Table 4.

Table 4. Results of the independent sample t-test for science understanding.

		Levene's Test for Equaty of Variance		t-test for Equality of Means					99% Confidence Interval of The Difference	
		F	Sig.	t	df	Sig. (2tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Scientific Understanding	Equal variance assumed	0.018	0.892	5.85	64	<0.001	5.57	0.95	3.04	8.10
	Equal variance not assumed			5.85	64	<0.001	5.57	0.95	3.04	8.10

Based on the table above, the Sig. (2-tailed) value is <0.001, which is less than 0.05. This indicates a significant difference in learning outcomes between the experimental and control classes in terms of scientific understanding. According to the decision-making criteria, H_0 is rejected and H_a is accepted. Therefore, it can be concluded that there is a difference in the average learning outcomes in scientific understanding between the experimental and control classes. The table also shows that the average learning outcomes of the experimental class are higher than those of the control class, with the difference being statistically significant.

In this study, data was obtained based on observation sheets used to assess the process skills of students during the learning process. The observation sheet for process skills consists of 7 indicators, which can be seen in Table 5.

Table 5. Process skills indicators.

No.	Process Skills Indicators
1	Observing
2	Questioning and predicting
3	Planning and conducting investigations
4	Processing and analyzing data
5	Creating
6	Evaluating and reflecting
7	Communicating results

Scoring for the process skills is done using a Likert scale, with scores of 1 (insufficient), 2 (sufficient), or 3 (good) to determine the assessment category. The results are then converted to a scale of 100. An Independent Sample t-Test is performed on the process skills data to compare the means of the two independent sample groups using IBM SPSS Statistics 27 for Windows. The results of the Independent Sample t-Test for process skills are presented in Table 6.

Based on Table 6, the significance value from Levene's test indicates that the data have equal variance (homogeneous). The Sig. (2-tailed) value shows a statistically significant difference in the average learning outcomes between the experimental and control classes. The average process skills of the experimental class are higher than those of the control class, with a 99% confidence interval confirming the existence of a mean difference. This demonstrates that the implementation of the PjBL model has a significant impact on student learning outcomes. The learning outcomes of students taught using the PjBL model are significantly higher compared to those taught using the Problem-Based Learning model.

This difference is also supported by statistical analysis, where the t-value and significance indicate that the mean difference between the two groups is not due to chance but rather the result of the PjBL model's implementation.

Table 6. Results of independent sample t-test for process skills.

		Levene's Test for Equaty of Variance		t-test for Equality of Means					99% Confidence Interval of The Difference	
		F	Sig.	t	df	Sig. (2tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Process Skills	Equal variance assumed	0.02	0.86	4,49	64	<0,001	4,47	0.99	1,83	7,11
	Equal variance not assumed			4,49	63,97	<0,001	4,47	0.99	1,83	7,11

The data analysis in this study revealed a significant increase in the average posttest scores of scientific understanding in the experimental class compared to the control class, with the difference being statistically significant. This indicates that the model effectively aids students in developing a deeper understanding of scientific concepts, enabling them to construct contextual knowledge. Furthermore, the active involvement of students in exploration and problem-solving related to real-world issues, such as renewable energy projects, aligns with constructivist theory. This theory emphasizes that understanding is achieved through authentic experiences encountered by students during the learning process [5]. Additionally, PjBL helped students better understand concepts by connecting existing theory with its practical application. Students could relate scientific theory to real-life situations, consistent with findings [22] that PjBL enables students to develop knowledge and understanding more deeply because they are directly involved in real-life situations. This type of learning trains students to find solutions to problems through project-based exploration. The lowest and highest science comprehension scores achieved by students are presented in Table 7.

Table 7. Science comprehension scores.

	Experimental Class		Control Class	
	Pretest	Postest	Pretest	Postest
Minimum Values	33	74	36	67
Maximum Values	54	89	60	84

Based on the scientific understanding test, which included questions of varying difficulty levels aligned with Bloom's taxonomy (C3, C4, C5, and C6), differences were observed between the pretest and posttest scores in the experimental class. Lower scores were attributed to students' initial lack of understanding of renewable energy and their unfamiliarity with higher-order questions requiring in-depth analysis. Higher scores were achieved by students with some prior knowledge, although it was not yet optimal. After the implementation of PjBL, the lowest posttest scores were still due to difficulties in tackling higher-order questions, particularly C5 and C6. However, the highest scores reflected active participation, improved concept comprehension, and the ability to analyze complex questions effectively. In the control class, pretest scores were slightly higher than those in the experimental class. However, after direct instruction through lectures and discussions, the posttest scores increased by a smaller margin compared to the experimental class. This indicates that direct instruction is less effective in enhancing students' scientific understanding. In contrast, the PjBL model had a more profound impact as it allowed students to build contextual knowledge through active and meaningful learning experiences. The lowest and highest scores obtained by students through the process skills observation sheet are shown in Table 8.

Table 8. Process skills observation sheet scores.

	Experimental Class	Control Class
Minimum Values	76,19	71,42
Maximum Values	85,71	80,95

In the process skills observation sheet with PjBL, the lowest scores in the experimental class were due to students not achieving maximum scores on the indicators of questioning and predicting. In this case, students only made tentative guesses without asking simple questions related to the material or writing them down in the LKPD (Student Worksheet), resulting in a score of 1 out of a maximum of 3. Additionally, in the "creating" indicator, students scored 1 because they created the project but did not develop ideas for solving the project or make improvements based on the feedback provided. The highest scores were achieved when students almost reached the maximum score for each indicator during the learning process. However, for the "processing and analyzing data and information" indicator, students did not include conclusions from their ideas in the LKPD. In the "communicating results" indicator, students received a score of 2 because they were unable to answer questions from other groups effectively regarding their projects. In the control class with PBL and simple practical activities, the lowest scores were due to students not achieving maximum scores on the indicators of questioning and predicting, creating, and evaluating and reflecting. The highest scores in the control class were achieved because students still did not maximize their performance on the questioning and predicting, creating, and evaluating and reflecting indicators.

Based on the data, the average process skills in the experimental class were higher compared to the control class, which indicates that the implementation of the PjBL model had a significant impact on students' learning outcomes. This success is attributed to the PjBL syntax that integrates active learning activities with the development of students' process skills. In the first stage of the learning process, students were encouraged to identify real-world problems related to renewable energy. This process helps students sharpen their abilities to observe, question, and predict solutions to the questions, aligning with the process skills indicators used. During this stage, students also gain relevant learning experiences, which is consistent with [22] who stated that investigating problems can significantly enhance students' conceptual understanding. The next stage, project planning, provided students with the opportunity to collaborate in groups to design miniature power plants. Through this activity, students not only honed their planning and investigative skills but also were encouraged to think creatively and innovatively. In this process, students learned how to manage information, determine tools and materials, and develop a systematic work plan for the project. This planning stage also fostered a sense of responsibility among students for completing the project in groups, which is important for the development of teamwork skills. [23] emphasized that collaboration in PjBL strengthens students' understanding of science concepts in a more applicative and contextual way.

The stage of creating a schedule for the project implementation and monitoring will teach students the importance of time management, ensuring they work according to the pre-established schedule while evaluating each step of the process. Meanwhile, the teacher will monitor the progress of the project. In this stage, students will enhance their ability to process and analyze the data and information they gather. Research by [24] indicates that active monitoring by the teacher in PjBL not only improves learning outcomes but also fosters students' interest in physics, which positively impacts their learning performance. In the assessment stage, students present the miniature power plants they created to their classmates. This involves the ability to communicate results clearly and logically, as well as evaluating and reflecting on their group's performance. Students not only demonstrate their mastery of concepts but also develop public speaking skills, receiving constructive feedback in the process. This aligns with research by [23], which stated that PjBL encourages students to produce science-based work that is not only academically relevant but also has practical applications. This process trains students to think critically about their work and provides opportunities to improve any shortcomings. The final stage, evaluation, gives students the opportunity to reflect on the entire learning process, including the challenges and successes they encountered. This helps students identify their strengths and weaknesses. Such evaluation also strengthens students' self-confidence in applying physics concepts to real-world situations.

The PjBL model has been proven effective in enhancing science understanding and process skills because it promotes active, collaborative, and real-world problem-based learning. This aligns with previous research that emphasizes the effectiveness of PjBL in improving learning outcomes, especially in subjects involving investigation and the application of scientific concepts. Overall, this study reinforces the finding that PjBL is an outstanding learning approach in integrating theory with practice. The structured syntax of PjBL allows students to deeply understand physics concepts while also developing process skills. By placing students at the center of learning, PjBL encourages active engagement, collaboration, and creativity, making it a highly suitable approach for the Merdeka Curriculum, which emphasizes contextual and project-based learning.

4. Conclusion

The results of the study showed that the average posttest scores for scientific understanding and the process skills observation sheets in the experimental class were higher compared to the control class. Based on these findings, there is a significant difference in both scientific understanding and process skills between the experimental and control classes. Therefore, it can be concluded that learning with the Project-Based Learning (PjBL) model on renewable energy topics can effectively enhance students' scientific understanding and process skills.

Acknowledgments

The author would like to express special thanks to all the parties at SMA Negeri 3 Bengkulu Tengah for granting permission and supporting the implementation of this research. The author also appreciates the Physics Education Study Program at the University of Bengkulu, particularly for providing the MBKM research program.

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