Jurnal Pendidikan Fisika
Vol. 14 No. 1, Juni 2025_84-96
DOI: 10.24114/jpf.v14i1.66526
p-ISSN: 2552-732X
e-ISSN: 2301-7651

Research Article

OPEN ACCESS

Students' System Thinking Skills through Project Based Learning with STEM Approach (PJBL-STEM): A Quasi-Experimental Study

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INFO ARTIKEL

Article History:
Submitted: 21-06-2025
Revised : 25-06-2025
Accepted : 27-06-2025
Published: 29-06-2025

Keywords:
PJBL-STEM;
System Thinking;
Renewabel Energy;
Wind Energy.

Kata Kunci:
PJBL-STEM;
Berpikir Sistem;
Energi Terbarukan;
Energi Angin.

ABSTRACT

Students have difficulty understanding physics concepts because they cannot connect them with everyday life. As a result, they study concepts separately and do not understand the relationships between concepts, especially on the topic of renewable energy, which are interconnected and play an important role in future life. This study aims to analyze the influence of the STEM-based Project-Based Learning model on students' system thinking abilities. A quantitative approach was used with a quasi-experimental design in the form of a Nonequivalent Control Group Design. The sample consisted of 62 tenth-grade students divided into experimental and control classes. The experimental class received the PJBL-STEM treatment, while the control class used the Problem Based Learning model. The highest improvement was observed in the coherent indicator, while the lowest improvement was in the intermediate indicator. These findings indicate that PJBL-STEM is effective in enhancing students' system thinking abilities, with an N-Gain value of 0.76 in the high category. This research is beneficial as an alternative learning strategy that can develop students' thinking skills and contribute to designing learning that is relevant to students' real-life contexts.

ABSTRAK

Siswa mengalami kesulitan memahami konsep fisika karena tidak bisa menghubungkannya dengan kehidupan sehari-hari. Akibatnya, mereka mempelajari konsep secara terpisah dan tidak memahami hubungan antar konsep, terutama pada topik energi terbarukan yang saling berkaitan dan memiliki peran penting bagi kehidupan di masa depan. Penelitian ini bertujuan untuk menganalisis pengaruh model Pembelajaran Berbasis Proyek berbasis STEM terhadap kemampuan berpikir sistem siswa. Pendekatan kuantitatif digunakan dengan desain quasi-eksperimental dalam bentuk Nonequivalent Control Group Design. Sampel terdiri dari 62 siswa kelas sepuluh yang dibagi menjadi kelas eksperimen dan kelas kontrol. Kelas eksperimen menerima perlakuan PJBL-STEM, sementara kelas kontrol menggunakan model Problem Based Learning. Peningkatan tertinggi terdapat pada indicator koheren, sementara peningkatan terendah terdapat pada indikator intermediet. Temuan ini menunjukkan bahwa PJBL-STEM efektif dalam meningkatkan kemampuan berpikir sistem siswa, dengan nilai N-Gain sebesar 0,76 dalam kategori tinggi. Penelitian ini bermanfaat sebagai alternatif strategi pembelajaran yang mampu mengembangkan keterampilan berpikir siswa serta memberikan kontribusi dalam merancang pembelajaran yang relevan dengan konteks kehidupan nyata siswa.

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INTRODUCTION

Physics is the foundation for many technologies and phenomena around us, yet many students struggle to relate physics concepts to real-life situations (Sitompul, 2022). These difficulties often arise in problem-solving, especially at the planning and execution stages (M. Saputri et al., 2024), where 48% of students struggle to understand the problem and 52% have difficulty planning the solution (Y.H.M. Yusuf et al., 2022). Specifically, on the topic of renewable energy, students are unable to understand the connection between theory and concepts, which impacts their learning outcomes due to a lack of ability to apply physics principles in everyday contexts (Tatsar et al., 2022). Data shows that students' basic understanding of renewable energy only reaches an average of 56.3% (Sunaryo et al., 2023). The less effective lecture-based learning method exacerbates this problem, making it difficult for students to apply physics concepts in their daily lives (Arafah, 2020).

The difficulty in understanding this concept has a significant impact, making physics feel difficult and unvaried, which ultimately reduces students' motivation to learn (Vuztasari & Tsania Nur Diyana, 2024). The impact is not only limited to suboptimal learning outcomes (Sunaryo et al., 2023), but also to the low ability of students to apply physics concepts and relate theory to real-world practice (Nurhaniah et al., 2022). Furthermore, these difficulties indicate that students' systems thinking skills have not yet developed, specifically their ability to understand the interconnections between components within a system.

The ability to think systemically is important for understanding the complexities of the modern world and providing a strong foundation for education and application in various disciplines (Arnold & Wade, 2015). Senge (1991) defines it as a way of thinking comprehensively about all components of an organization as an interconnected whole. This ability not only helps students understand the relationships between components holistically but also develops critical thinking skills (Chaidir et al., 2024). Unfortunately, system thinking skills in Indonesia are still low, with most students only able to reach levels 1 and 2 (Nuraeni et al., 2020), and even unable to analyze the relationships between components in the system comprehensively (Effendi et al., 2023).

Student-centered learning, such as project-based learning, can be a solution to enhance system thinking skills. Supported by the findings of Sanuaka et al. (2022), STEM can be used as the primary choice for an approach because it has been proven to improve student learning outcomes in physics education. The PJBL-STEM model has proven capable of developing various skills (Baran et al., 2021), because in its stages, students are directed to identify problems, gather information to solve the problems, design, create, and build projects as a form of a system (Laboy-Rush, 2010). Activities with this learning model can achieve system thinking indicators such as analyzing relationships, building interaction patterns, and predicting their impact on the (Meilinda et al., 2018), while also actively involving students, making learning more effective (Nurhidayah et al., 2021).

The combination of Project-Based Learning (PJBL) and STEM (Science, Technology, Engineering, and Mathematics) can enhance learning outcomes, create a more engaging educational experience, and shape students' career aspirations. Students show a positive response to the integrated PJBL-STEM approach (Tseng et al., 2013). Furthermore, STEM in PJBL challenges and inspires students by teaching them to think critically, analyze, and strengthen higher-order thinking skills (Capraro et al., 2013). STEM education requires students to develop expertise in various disciplines (such as science, technology, engineering, and mathematics) while addressing real-world problems that are often open-ended and do not have predetermined solutions (Ouyang & Xu, 2024).

The Project-Based Learning STEM (PJBL-STEM) model has been shown to be effective in fostering students' problem-solving abilities (Purwaningsih et al., 2020), higher-order thinking (Fitriyani et al., 2020), and creativity (Millen & Supahar, 2023). These competencies are essential for developing systems thinking, a skill increasingly emphasized in science education. Despite its recognized benefits, the PJBL-STEM model has not been extensively explored in the context of assessing students' systems thinking, particularly within physics education. Recent efforts have begun to explore how integrating contemporary issues—such as renewable energy—into the curriculum can deepen students' conceptual understanding and analytical skills. Within this framework, engaging high school students in the design and construction of simple teaching aids related to wind energy offers a promising pathway to cultivate systems thinking. Therefore, this study aims to examine the potential of the PJBL-STEM model in enhancing students' systems thinking skills on renewable energy materials, particularly wind energy.

RESEARCH METHODE

The research was conducted at a high school located in the South Tangerang area. This study uses a quantitative approach with a quasi-experimental design method with a Nonequivalent (Pretest and Posttest) Control-Group Design (Creswell, 2014). This study included 258 students in tenth grade. 31 students from class X-1 were the control class, and 31 students from class X-3 were the experimental class. The purposive sampling technique was used to select the sample. The division of the control and experimental classes was carried out by the school, so it can be said that the conditions of the two classes were the same. The research design is illustrated in Figure 1.

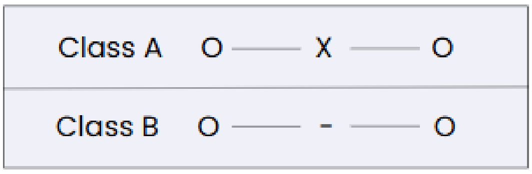


Figure 1. Nonequivalent (Pretest and Posttest) Control-Group Design (Creswell, 2014)

In this study, Class A served as the experimental group, while Class B functioned as the control group. Both classes underwent pre-testing and post-testing, but only the experimental group (Class A) was exposed to the PJBL-STEM instructional model. The research examined two key variables: the independent variable, which was the Project-Based Learning model integrated with STEM (PjBL-STEM), and the dependent variable, representing students' system thinking skills. The five phases of learning in the PJBL-STEM process developed by Laboy-Rush (2010) are as follows:

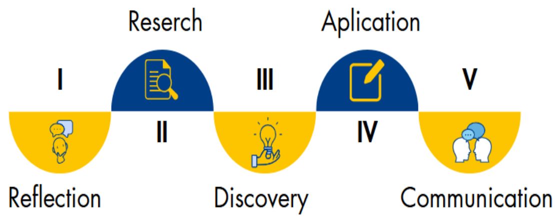


Figure 2. PJBL-STEM Stage

The experimental class with the application of the PJBL-STEM model goes through several stages. The first stage is Reflection, where students identify the energy crisis problem as a consequence of fossil fuel use. Then, in the research stage, students gather information to find solutions to the problem, one of which is the use of wind energy. Students are directed to find the principles of using that energy and its components. Students develop ideas that incorporate aspects of science, technology, engineering, and mathematics and design them as initial concepts for teaching aids. The activity is included in the Discovery stage.

Furthermore, the students apply their design in the form of a teaching aid, with the success indicator being a light. The tool underwent its first trial to test its function and working system. After conducting the first trial, the students proceeded to the redesign phase based on the evaluation results from the first trial. Students analyze the weaknesses and strengths of the teaching aids. Next, the students communicate (Communication) in front of the class in turns. Students present the results of their projects, such as the components, work steps, initial test results, differences in the tools before redesigning, and the uniqueness of their tools.

The control class implemented the learning model used by their teacher, which is the Problem Based Learning model. The control class also received a pretest before starting the lesson. The first stage is orientation, where students are introduced to the crisis of non-renewable energy usage. Then, the students discuss in groups to complete a worksheet on solutions to address the issues at hand. Students conduct an investigation to find information on renewable energy from various sources. Next, the students present the discussion results in printed media such as posters.

Students present their findings that have been discussed in the printed media through alternating presentations in class. Another group is given the opportunity to assess and evaluate the results of the discussion that has been conducted on energy problem solutions. After everyone presented the discussion results, the students reflected on the learning that took place and filled out a systems thinking posttest.

The pretest and posttest questions of the system thinking instrument refer to (Meilinda et al., 2018) which have been developed from the framework (Boersma et al., 2011). These system thinking indicators are mapped into four levels: System Thinking Indicator I (prerequisite), which includes the basic elements for system thinking; System Thinking Indicator II (basic), which includes understanding the relationships between system elements; System Thinking Indicator III (intermediate), which includes a more complex analysis of system dynamics; and System Thinking Indicator IV (coherent), which includes a holistic understanding of the system with deep concept integration. The results of the instrument trial based on the indicators presented in Table 1.

Table 1. Pearson correlation value of the system thinking instrument trial

Levels	Indikator	Items	Pearson Correlation	Sig.	Description	Interpretation
I	Identifying components and processes within a system	1	0.353	0.020	Valid	Low
		2	0.139	0.373	Not Valid	Not Worthy
	Understanding the relationship between components, such as the relationship between wind and electricity, by analyzing the function or role of those components	3	0.359	0.018	Valid	Low
		4	0.367	0.015	Valid	Low
	Mapping the phenomenon or concept of wind energy on specific components of the Wind Power Plant system	5	0.578	0.000	Valid	Enough
		6	0.416	0.006	Valid	Enough
II	Analyzing the relationship of a concept at one level with the level above it or the level below it	7	0.414	0.006	Valid	Enough
		8	0.211	0.174	Not Valid	Not Worthy
	Organizing system components, processes, and interactions among the three within a single system framework	9	0.104	0.508	Not Valid	Not Worthy
		10	0.501	0.001	Valid	Enough
	Identifying the feedback process occurring in the system	11	0.550	0.000	Valid	Enough
		12	0.105	0.504	Not Valid	Not Worthy
III	Generalizing from the patterns formed by the system	13	0.328	0.032	Valid	Low
		14	0.613	0.000	Valid	High
	Designing interaction patterns of system components that can be detected within a closed system	15	0.523	0.000	Valid	Enough
		16	0.553	0.000	Valid	Enough
	Creating/developing a model that depicts the position of all components within the framework of a closed system in 2D/3D, both horizontally and vertically	17	0.704	0.000	Valid	High
		18	0.606	0.000	Valid	High
IV	Predicting/retrospecting behaviors that emerge from the system due to interactions	19	0,370	0.015	Valid	Low
		20	0.460	0.002	Valid	Enough

Levels	Indikator	Items	Pearson Correlation	Sig.	Description	Interpretation
	between components within the system					
	Predicting / retrospecting the impact that arises from an intervention in the system using a model or pattern that has been designed	21	0.321	0.036	Valid	Low
		22	0.497	0.001	Valid	Enough
	Implementing a new system pattern based on prediction/retrospection results	23	0.581	0.000	Valid	Enough
		24	0.237	0.126	Not Valid	Not Worthy
		25	0.735	0.000	Valid	High
		26	0.270	0.080	Not Valid	Not Worthy

The instruments in this study have been tested by experts for construct, content, and language validation. The content validation results show CVR values for material, construct, and language of 0.807; 0.919; and 0.888, respectively, while the CVI values are 0.903; 0.959; and 0.944, respectively. This indicates that the instrument is ready to be tested. After the instrument was tested with the involvement of 43 students, it was found that 20 out of 26 multiple-choice questions were declared valid, with a reliability test result yielding an Alpha Cronbach value of 0.828.

Descriptive statistics were computed to analyze central tendency and dispersion measures for all questionnaire items and individual indicators. Given the sample size (N < 100), the Shapiro-Wilk test assessed data normality from the systems thinking assessment, while Levene's test evaluated homogeneity. For inferential analysis, we employed both parametric (Independent Samples t-test for pretest comparisons) and nonparametric (Mann-Whitney U test for posttest differences) approaches. Effect size analysis quantified the magnitude of observed effects, with interpretation guidelines provided in Table 2.

Table 2. Interpretation of Cohen's d effect size values

Value	Description
<0.2	Small
0.2-0.8	Medium
>0.8	Large

This study also identifies the effectiveness of the learning model intervention used in the experimental and control classes with the N-Gain test. The interpretation of the N-Gain score acquisition is presented in Table 3.

Table 3. Interpretation of N-Gain Values

Value	Description
<0.3	Low
0.3 – 0.7	Medium
>0.7	High

RESULT AND DICUSSION

This study examined the impact of a STEM-integrated Project-Based Learning (PJBL-STEM) instructional model on students' systems thinking competencies in the context of wind energy education. Descriptive statistical results are presented in Table 4.

Table 4. Results of the system thinking ability test for the experimental class and the control class

Class	N	Range	Min-Statistic	Max-Statistic	IQR	Median	Mean	SD
Pre-test Eksperiment	31	65	5	70	30	30	34.19	17.517
Post-test Eksperiment	31	40	60	100	15	85	85.32	10.796
Pre-Test Control	31	75	10	85	20	40	41.45	19.841
Post-test Control	31	75	15	90	15	75	74.19	15.816

Table 4 shows that the average pretest score of the experimental class (34.19) is not much different from the control class (41.45). Similar to the posttest average, both classes received scores that were not significantly different, namely (85.32) and (74.19). Although the experimental class received posttest scores that were not significantly different, the experimental class consistently demonstrated superior performance relative to the control class, attributable to the instructional model intervention implemented specifically in the experimental group. Importantly, although the control class initially demonstrated superior pretest performance compared to the experimental class, this baseline difference was unrelated to any instructional intervention. To examine our research hypothesis, we conducted prerequisite analyses (normality and homogeneity tests) prior to performing inferential statistical tests. Table 5 presents the detailed normality test results.

Table 5. The results of the normality test for both classes

	Experimental class		Control class	
	Pre-test	**Post-test**	**Pre-test**	**Post-test**
Sig.	0.150	0.086	0.077	0.000
Shapiro Wilk Test	(Sig<0.05 = Data is not normally distributed) (Sig>0.05 = Data is normally distributed)			
Decision	Data is normally distributed	Data is normally distributed	Data is normally distributed	Data is not normally distributed

For the three datasets, the pre-test scores of the experimental class, the post-test scores of the experimental class, and the control class scores, the Shapiro-Wilk test results indicate a normal distribution. However, the post-test scores of the control class show a non-normal distribution. Next, the analysis used a t-test to compare the pre-test performance of both classes; the comparison results are presented in Table 6.

Table 6. Comparison test results of pretest scores of experimental and control classes

	Eksperiment Class	Control Class
N	31	31
Mean	34.19	41.45
t	-1.527	-1.527
Sig	0.132	0.132

Based on the statistical test results, the sig value was obtained (0.132>0.05). This shows there is no significant difference between the two classes in the pretest score.

Table 7. Results of the homogeneity test

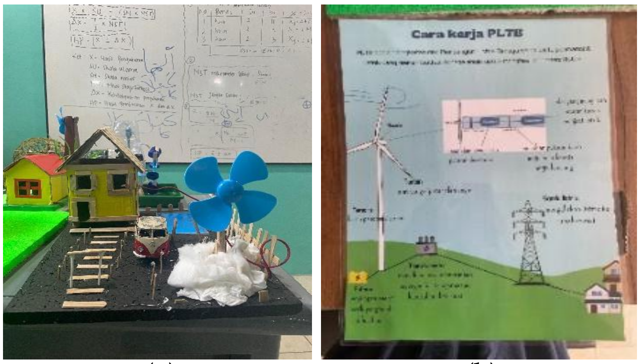
	Based on Mean	Based on Median
Sig.	0.210	0.242
Levene Test	(Sig<0.05 = Data is not homogeneous) (Sig>0.05 = Homogeneous data)	
Decisions	Homogeneous data	

Homogeneity testing was conducted to ensure that both the experimental and control classes exhibit similar data distribution variables. The post-test results from both classes show homogeneity, as indicated in Table 7. However, because the post-test data from the control class deviates from the normality assumption, which is a requirement for parametric testing, the non-parametric Mann-Whitney U test was used. The results of the analysis are presented in Table 8.

Table 8. Results of the comparison test of post-test scores between the experimental and control classes

Systems Thinking Skill	N	Mean Rank	Sum of Rank	p
Post-test Eksperimen	31	38.37	1189.50	0.002
Post- test Control	31	24.63	763.50	

Post-test data from both experimental and control classes were analyzed using the Mann-Whitney U test to assess differences in systems thinking ability. The analysis revealed statistically significant differences ($p < 0.05$) between groups, with the experimental class demonstrating superior performance (median = 85.00) compared to the control class (median = 75.00). A large effect size was observed (Cohen's d = 0.82), confirming the substantial impact of the intervention. Comparative outputs from both groups are visually presented in Figure 3.



(a) (b)

Figure 3. (a) Experiment Class (b) Control Class

Figure 3 shows the differences in project representation between the experimental class and the control class. In figure 3a, the experimental class students produced a three-dimensional model of a wind power plant (PLTB) creatively designed using various components such as propellers, miniature houses, and cables to symbolize the electrical system. This project requires students to not only understand the concept of wind power plants (PLTB) theoretically but also to apply it in a tangible form through the process of system design and analysis, reflecting the achievement of system thinking ability indicators.

Meanwhile, image 3b from the control class only shows a two-dimensional poster containing a descriptive explanation of the PLTB workflow. This presentation tends to be passive and does not encourage students to explore the relationships between components in depth. This is reflected in the graph of students' system thinking ability results. The experimental class experienced significant improvements across all indicators, such as the prerequisite indicator which increased from 34.83 to 80.64, the basic indicator from 36.55 to 88.17, the intermediate indicator from 35.48 to 77.95, and the coherent indicator from 36.02 to 95.16. The control class also experienced improvement, but none surpassed the experimental class.

This difference indicates that the PJBL-STEM approach applied in the experimental class is more effective in fostering system thinking skills through the active involvement of students in problem-based projects and real system engineering. The comparison of the average system thinking ability scores based on indicators in both classes is presented in Figure 4.

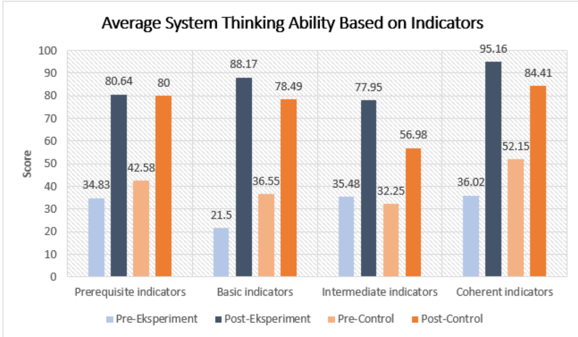


Figure 4. Diagram of the average of experimental and control class system thinking indicators

Figure 4 shows the pretest and posttest results for both classes. Overall, the ability to think systematically in both the experimental and control classes has improved. But two out of four indicators hypothetical high. The post-test scores in the experimental class for the basic indicator (88.17) and the coherent indicator (95.16). The increase in these scores indicates that students are able to understand the relationships between components in a system and analyze the impacts occurring within the system. Meanwhile, the indicator that experienced the least increase is the intermediate indicator, both in the experimental class (77.95) and the control class (56.98), which involves analyzing more complex systems such as generalizing within the system and making all components interact with each other as a system.

Next, the effectiveness analysis of the interventions given to both classes to improve students' system thinking skills is measured using N-Gain analysis. The quantitative results of this effectiveness assessment are detailed in Table 9.

Table 9. Average N-Gain Results of the Experimental Class and Control Class

Class	Value of N-Gain	Category
Eksperiment	0.76	High
Control	0.48	Medium

Table 9 presents the N-Gain analysis results for both experimental and control groups. The experimental class demonstrated substantial improvement in systems thinking ability (N-Gain = 0.78), while the control class showed more moderate gains (N-Gain = 0.48). Although both groups exhibited progress, the experimental group's normalized gain score was significantly higher, indicating greater intervention effectiveness. This indicates that students' system thinking abilities improve more when using the PJBL-STEM model. To determine which aspects have improved, an N-Gain test analysis was conducted for each indicator presented in Figure 5.

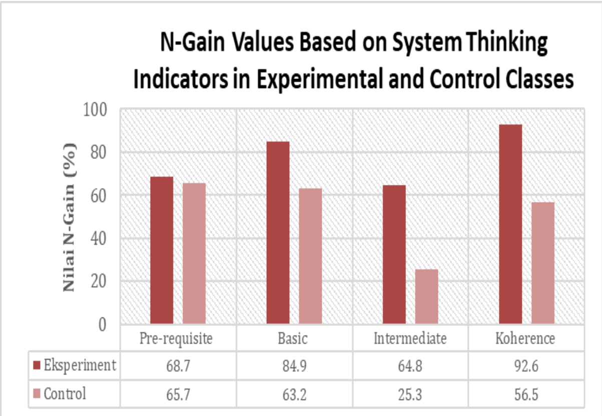


Figure 5. N-Gain Value Diagram Based on Second-Class System Thinking Indicators

As shown in Figure 5, an analysis of N-gain percentage averages reveals distinct patterns of improvement in systems thinking indicators between the experimental and control groups. The experimental group achieved its largest gains in coherent thinking, whereas the control group saw the most progress in basic indicators. Interestingly, both groups made very little advancement in intermediate indicators, although the experimental group's N-gain values were still higher across the board. For a complete categorical interpretation of these findings, refer to Table 10.

This study was conducted using the PJBL learning model based on the STEM approach on renewable energy materials, specifically wind energy. The research results show that the PJBL-STEM model significantly affects system thinking abilities with a large effect size. These findings are in line with the research by Sukarma et al. (2024), which states that students can achieve systematic thinking competence after engaging in PJBL-STEM activities. Additionally, a study by Tulinao and Bailey (2024) also revealed that the integration of PJBL in the STEM context for junior high school students positively enhances system thinking and competence, thereby benefiting both academic performance and out-of-class experiences. Based on these findings, the use of the PJBL-STEM model becomes very important to achieve the expected system thinking indicators.

Table 10. N-Gain Test Results Based on System Thinking Indicators

Indicator	Eksperiment		Control	
	Value	**Category**	**Value**	**Category**
Prerequisite	68.7	Medium	65.7	Medium
Basic	84.9	High	63.2	Medium
Intermediet	64.8	Medium	25.3	Low
Koheren	92.6	High	56.5	Medium

Although PJBL-STEM significantly improves system thinking skills, challenges arise with one of the indicators, namely the third indicator, which shows the lowest increase. This indicator measures students' ability to make system generalizations, design interactions between components, and model system frameworks (Meilinda et al., 2018). These findings are in line with Nuraeni et al. (2020), who reported that students struggle to reach levels three and four in systems thinking. Furthermore, the research by S. A. Saputri and Suryadi (2024) found that students' abilities only reached level one, presumably due to weak understanding in identifying and analyzing system feedback. On the other hand, Habibah et al. (2024) showed a significant increase (effect size 0.54), although it is still considered low. This difference indicates that contextual factors, such as the depth of STEM integration or project complexity, may influence the achievement of certain indicators.

This study also found that the fourth indicator experienced the greatest increase, which measures students' ability to evaluate the impact of a system and formulate solutions. This achievement is closely related to problem-solving skills, as evidenced by Subekti et al. (2025), who state that PJBL-STEM effectively enhances these competencies. Similar findings from Parno et al. (2020) reinforce this: the PJBL-

STEM model resulted in a significant increase (Cohen's *d* = 1.65; very large category) in students' problem-solving skills on the topic of electromagnetic induction compared to conventional PJBL. This indicates that students are not only able to critically analyze project outcomes but also realistically predict their impact through direct experience. Additional support comes from Lin et al. (2018), who assert that the integration of 3D models in PJBL-STEM enhances student engagement and understanding. Additionally, the use of audiovisual media Sihombing (2023) has proven to minimize misunderstandings, thereby contributing to the successful achievement of this indicator.

Another interesting finding in this study is the effect size of 0.82, which falls into the large category, indicating a significant influence of the PJBL-STEM model on system thinking skills. This value is supported by several factors such as students' interest in learning, thorough preparation, and adequate school facilities (Muchtar et al., 2025). Post-test results show that the experimental class consistently achieved higher scores than the control class on all system thinking indicators. This consistency can occur because the PJBL-STEM approach is highly relevant to renewable energy materials and effectively engages students in learning. According to research conducted by Diana et al. (2021), PJBL-STEM has become one of the widely used learning models and can enhance its effectiveness in application.

More specifically, the learning process in the experimental class involves critical activities such as direct identification of system components, analysis of the relationships between components, and predicting the impact of a tool or system. These activities directly support the development of system thinking skills in accordance with the indicators developed (Boersma et al., 2011; Meilinda et al., 2018). Furthermore, the findings of Lin et al. (2021) reinforce that such activities not only develop system thinking skills but also stimulate students' creative ideas and engineering design thinking through the PJBL-STEM model.

A significant improvement was also observed in the second indicator after the fourth indicator. This indicator measures students' ability to analyze the relationships between components. This can occur due to the implementation of the STEM approach. In line with the findings of Suryadi et al. (2021) that students' correlational reasoning abilities improve through a STEM-based approach. Furthermore, Prajoko et al. (2023) explain that PjBL-STEM enables students to understand concepts comprehensively, not as separate pieces of knowledge, but as interconnected systems. With this approach, PjBL-STEM not only develops technical-cognitive skills but also builds social-environmental awareness, making it a learning solution relevant to global challenges (Rahmadhani, 2024).

This study also found that the PJBL-STEM learning model can enhance system thinking skills. The N-Gain results show that PJBL-STEM is effective in developing all aspects of system thinking skills with an N-Gain score of 0.76. Based on each indicator, the experimental class recorded higher N-Gain scores across all indicators, indicating that student involvement in STEM-based projects strengthens their systemic understanding. This confirms that the STEM approach in project-based learning is capable of encouraging students to understand concepts through direct practical application and to strengthen thorough analysis (Rarastika et al., 2025; Yaqutunnafis, 2024).

The indicator with the highest improvement was found in the coherent indicator, which is the ability to predict and retrospect the impact of a system. This shows that PJBL-STEM encourages students to think ahead and design systemic solutions. To achieve this indicator, students need problem-solving skills. With the STEM approach, students can enhance their high-level problem-solving abilities (Alatas & Yakin, 2021; Purwaningsih et al., 2020). In addition, this method also trains students to think critically and creatively in designing solutions that are not only effective but also sustainable, in accordance with the systemic patterns they learn (Fitriyani et al., 2020; Storina, 2022). With direct involvement in the project, students not only understand the system but are also able to evaluate the consequences and propose sustainable solutions.

Meanwhile, the lowest improvement was found in the intermediate indicators, which include the ability to generalize patterns and develop system models. These limitations may be caused by the lack of active participation from all members in group cooperation. The imbalance in contributions causes some students not to experience the system thinking process in its entirety. These findings are in line with Sanubari et al. (2024), who state that learning outcomes tend to decline when student participation in groups is uneven. Another possibility is caused by several factors such as similarities in content and activities, similar engagement, and similar guidance (Suryadi et al., 2024). Nevertheless, the N-Gain scores on this indicator remain higher in the experimental class compared to the control class, indicating that the PJBL-STEM approach still has a positive impact, albeit not optimal.

The implication is that PJBL-STEM can be a strategic approach to equip students with systemic thinking skills that are highly needed in facing complex real-world problems. However, more in-depth project design is needed to encourage students to reach the highest level of systemic thinking, as students begin to understand that concepts in learning are interconnected and form a dynamic system. Therefore, PJBL-STEM can be an alternative 21st-century learning model that not only transfers knowledge but also trains higher-order thinking skills relevant to real-life situations and global challenges. However, since this research was only conducted in the context of wind energy material and with limited implementation time, it is recommended that future research apply this model to other topics and design projects that can involve all group members more evenly.

CONCLUSION

This study shows that the implementation of PJBL-STEM learning significantly affects students' system thinking abilities with a large effect size. Students showed improvement in identifying components, understanding the relationships between components, understanding the working processes within a system, and analyzing cause and effect within an entire system. This is evident from the results showing differences in students' system thinking abilities on renewable energy materials, particularly wind energy, with a large effect size of 0.82. The application of this model is effective in improving students' systems thinking skills with an N-Gain score of 0.76. The implication of this finding is that the PJBL-STEM model could be an alternative approach that physics teachers can apply to develop students' system thinking skills through contextual and integrative project-based learning.

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