ISSN : 2549-2764 (ONLINE)
ISSN : 2337-604X (PRINT)
BERKALA ILMIAH PENDIDIKAN FISIKA
https://ppjp.ulm.ac.id/journal/index.php/bipf

The Effect of PjBL STEM Learning on Students' Systems Thinking Skills on Alternative Energy Materials

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DOI:10.20527/bipf.v12i3.18968

Received: 18 March 2024 Accepted: 20 August 2024 Published: 17 October 2024

Abstract
This study explores the effect of project-based learning (PBL) integrated with STEM on improving students' systemic thinking abilities. The study employed a quasi-experimental pretest-posttest control group design as its research method. The population consisted of 244 students enrolled in the tenth grade during the odd semester of the 2023-2024 academic year, and participants involved in the study were 68 tenth-grade students from one of the Islamic Senior High Schools of the State in Jakarta. The experimental group used PjBL STEM, while the control class used 5E learning (engagement, exploration, explanation, elaboration, and evaluation). The researcher developed a system thinking instrument adapted from Melinda based on pre-requirement, basic, intermediate, and coherent expert levels. In this study, data analysis used the non-parametric Mann-Whitney U test and Wilcoxon test. The research findings indicate a significant improvement in the system thinking ability of the experimental group students, while the control group's system thinking ability did not improve significantly. The results showed that the effect of PjBL STEM improvement in the experimental class was 0.54 (effect size) on students' systems thinking ability but was still in the low category and did not improve either in the control class. In addition, the level of systems thinking increased in the expert category, while the intermediate level did not increase. This study can be a reference for further research investigating the effect of PjBL STEM on students' systems thinking in different contexts.
Keywords: alternative energy; STEM PjBL; systems thinking

How to cite: Habibah, H., Lidya, N., & Suryadi, A. (2024). The effect of PjBL STEM learning on students' systems thinking skills on alternative energy materials. *Berkala Ilmiah Pendidikan Fisika*, 12(3), 371-382.

INTRODUCTION
Systems thinking is one of the essential thinking skills for students. Systems thinking skills are needed to understand environmental problems (Aspridanel et al., 2022), analyze complex thinking (Nuraeni et al., 2020), and make decisions in solving complex problems (Dawidowicz, 2012; Goralnik et al., 2012). In addition, systems thinking becomes an analytical skill that corresponds to increasing the ability to predict, design, and modify a system (Hamdu et al., 2021).

Systems thinking is a collection of complementary analytical abilities that enhance one's capacity to recognize and comprehend systems, forecast their behaviors, and design changes to them to achieve desired outcomes. Together, these abilities function as a system (Arnold & Wade, 2015). Whereas in Indonesia, students' systems thinking skills are still in the low category (Nuraeni & Aliyah, 2020).

System thinking is one of the high-level thinking skills, and it is closely related to science learning, including physics. Physics learning always emphasizes understanding very complex concepts. Many concepts from science lessons intersect (Lou et al., 2011). Understanding physics requires systems-thinking skills. Research by Hrin et al. (2017) showed that understanding occurs faster if students connect a concept. Although it is noted that this ability is a much-needed part of education, there are limitations in integrating systems thinking into education (Gilissen & Verhoeff, 2017), and students' level of systems thinking ability is lacking (Nuraeni et al., 2020).

Several attempts have been made to develop students' systems thinking skills. For example, research by Evagorou (2009) found that interactive learning using Stagecast Creator software triggered significant improvements in systems thinking skills during a relatively short learning process. In addition, Rachmat et al. (2023) showed that inquiry learning can also help improve students' systems thinking skills. Ekselsa et al. (2023) Their research stated that project-based environmental change learning can moderately improve students' systems thinking skills. By referring to the results of the research that has been done, it can be concluded that systems thinking can be enhanced through a student-centered learning approach.

One of the student-centered learning alternatives that has been widely studied lately is PjBL-STEM learning. PjBL-STEM is a learning approach that emphasizes the creation of products through the design process. The integrated PjBL-STEM model has additional benefits. Integrating STEM with PjBL allows students to explore ideas, create products, and advance their planning skills (Zahira, 2023). Among the advantages of the STEM method is that it can serve as a foundation for future development and help students become more independent, logical thinkers, creative problem solvers, and technologically literate (Kurniati et al., 2022; Stohlmann et al., 2012). Abdurrahman et al. (2019) showed that STEM learning could improve 21st-century skills, especially elementary school students' high-order thinking skills in science materials. In addition, the research results by Purwaningsih et al. (2020) stated there is an increase in problem-solving ability influenced by PjBL-STEM learning on momentum and impulse material, and students are better trained to solve problems in everyday life. The Pjbl STEM approach to the scientific curriculum can help students become human resources capable of thinking critically, creatively, systematically, and logically to meet the demands of 21st-century human resources and be prepared to face increasingly complex global challenges (Rahmania, 2021). Students who study STEM can apply their expertise to solve problems and get ready for life in the industry throughout the Fourth Industrial Revolution. (Alatas & Yakin, 2021; Putri, 2019; Suryadi et al., 2023; Utami & Nurlaela, 2021)

With the characteristics of PjBL-STEM learning, there is potential to develop students' systems thinking skills. Learning with PjBL-STEM facilitates students to think systematically, think logically, develop technological literacy, and solve problems in everyday life. However, exploring the effect of integrated PjBL-STEM in developing students' systems thinking is still limited.

The implementation of integrated PjBL-STEM learning needs to consider the subject matter. Reports of several studies have shown that PjBL-STEM learning can be implemented on various learning topics, including topics in physics learning (Megawati et al., 2023). Energy material is one of the materials that can facilitate students in integrated learning (Sirait et al., 2024). In this material, students think that renewable energy material is less attractive to learn and assume that it cannot make students feel systems with energy problems in real life. In addition, reports of petroleum reserves are dwindling, so they are not enough for the next ten years. This was conveyed by the Ministry of Energy and Mineral Resources in 2018. Through this topic, students are directed to apply solutions to energy problems in the form of alternative energy. This study explores the effect of integrated PjBL-STEM learning on improving students' systems thinking skills on solar energy materials.

METHOD

The research was conducted in the odd semester of the 2023–2024 school year at one of the Madrasah Aliyah Negri in Jakarta. This study used a quantitative approach with a quasi-experimental method with a pretest-posttest control group design that was nonequivalent (Creswell & Creswell, 2018). This study involved two classes randomly assigned as experimental and control classes. The school had already formed the classes, so the researcher could not change the students in the class. Both classes were given a pretest to measure the initial ability of students' systems thinking and a post-test to measure the final ability of systems thinking. The intervention was carried out in the experimental class, and the control class did not receive treatment as a comparison to ensure that the intervention and no other factors caused the changes in the experimental class. The research design is shown in Table 1.

Tabel 1 Pretest-posttest control group design

Group	Pretest	Treatment	Postest
Experiment	O_1	X_1	O_3
Control	O_2		O_4

The research was conducted at one of the Madrasah Aliyah, which is equivalent to a high school. Data collection was carried out for four meetings in October–December 2023. All grade X students in one of the MANs in Jakarta became the population in this study, which amounted to 244 students. Sampling was carried out using a purposive sampling technique. The participants involved in the study were class X-A students, totaling 34 people as a control class, and class X-E, totaling 34 people as an experimental class.

This research is divided into three stages. The first stage, preparation, involves preliminary studies, including observations, interviews, and literature searches related to STEM PjBL learning and systems thinking skills. Then, related experts prepare, guide, and test the instruments and modules for validity.

The second stage is the implementation stage in the control and experimental classes. Researchers give a pretest to measure the initial ability of thinking systems. In the control class, researchers provided the conventional 5E learning treatment that teachers usually do. In the experimental class, researchers provide learning treatment using STEM PjBL, which is conducted for four meetings or four weeks.

The first meeting begins with an opening with the principal. Then, students are divided into several groups, first introduced to renewable energy materials and STEM KIT, followed by carrying out activities in Guidebook 1, starting with identifying problems, conducting research, conducting activities to analyze the effect of the area of solar panels, conducting discussions related to the activities that have been carried out, and finally being given the task of designing an automatic garden light cover for the next meeting. All activities were carried out with the guidance of the research team. Meeting 2 began with doing the activities in Guidebook 2, starting with activities to analyze the effect of solar panel area and the effect of two solar panels if they are assembled in series or parallel, then conducting discussions related to the activities that have been carried out, and finally being given the task of designing an automatic garden light cover for the next meeting. All activities were carried out with the guidance of the research team. Meeting 3 was carried out by following Guide 3, which consisted of core activities: making a solar panel automatic garden light circuit. After the circuit was successfully made, students conducted an automation test on the circuit. The circuit is successful when the lights turn on during dark conditions and turn off during bright conditions. Based on the automatic garden lights, students identify the quality of the product and the improvements that need to be made by answering several questions in the discussion section. At the end of the guide, students are asked to assemble the circuit with the lamp frame assigned in the previous meeting. Meeting 4 begins by giving time to finalize the work on automatic garden lights and prepare to present the work. Then, each group will make a presentation, be assessed, and be given joint input by peers and the research team. Then, each group will redesign based on the input that has been given. This activity ends by giving awards to teams that make products and present them interestingly and according to the criteria to be achieved.

The study was conducted with two bazaar samples, namely the control class, using the conventional 5E method. This was done based on the results of interviews with teachers at the research site and adjusted to the teaching module that the teacher had prepared. Details of activities at meeting one: the teacher introduces the topic using interesting pictures and videos. Furthermore, students discuss in groups to stimulate thinking and activate their initial abilities related to the topic to be studied. After that, students are allowed to explore concepts actively through observation. The next group discussion discusses the results of student observations. The next step is for students to present their observations, including theories, concepts, and links to the theory that has been taught.

Furthermore, students are tasked with making group projects to apply the observations obtained. Students can also explore additional aspects of the topic discussed. Two projects that students have made are presented, and then other students ask questions about the presented project. Next, the teacher and students evaluate the material that has been learned. This step is important to identify areas that still need to be improved. Thus, the 5E method provides a holistic framework that ensures the learning process is structured and responsive to students' needs.

After that, the researcher gave the post-test to students in both control and experimental classes to determine the final ability of the students' system thinking. The third stage of the pretest and post-test results was processed by the researcher, who compared the results of the instrument data before and after treatment to determine the difference in improving students' system thinking skills in the experimental and control classes. Then, the researcher drew conclusions based on the data analysis obtained.

The scientific creativity test instrument developed by the researcher was adopted (Meilinda et al., 2018) and developed by experts (Boersma et al., 2011). The test instrument consists of 25 multiple-choice questions based on four levels of 12 indicators.

Table 2 System thinking indicators

Level	Indicator	Item Test Number
Pre-Requirement	Identify components and processes in a system.	1,2
	Identify the relationship between structure and function or role in system components at one level of organization.	3,4

Level	Indicator	Item Test Number
	Mapping solar energy phenomena and concepts to specific components of a solar power system	5,6
Basic	Analyze the relationship of concepts at one level with the level above or the level below.	7,8
	Organize system components, processes, and interactions between them in a system framework.	9,10
	Identify feedback processes that occur in the system.	11,12
Intermediate	Generalize the pattern formed by the system.	13,14
	Design interaction patterns for system components that can be detected in a closed system.	15,16
	Create or develop a model that describes the position of all components in a closed system framework in 2D/3D, both horizontally and vertically.	17,18
Coherent expert	Predicting or retrospecting the behavior that arises from the system due to interactions between components in the system	19,20
	Predict or reflect on the impact that arises from interventions on the system using the model or pattern that has been designed.	21,22
	Apply new system patterns based on the results of prediction and reflection.	23,24,25

Three experts have validated the research instruments used. The instruments in this study were tested by experts for construct and content validation. The results of expert validation: Several inputs given by experts have been corrected by researchers so that the results of the instrument are validated. The instrument was also tested by involving 85 participants. The validation test used the Pearson product-moment technique, which reported that 25 out of 25 multiple-choice questions were declared valid, with the reliability test obtaining an Alpha Cronbach value of 0.73.

Data was collected by giving the control and experimental classes pretests and post-tests. A descriptive statistical test determined the data concentration and distribution size. This study's descriptive statistical tests include mean, median, standard deviation, and interquartile range. The Shapiro-Wilks normality test was used to assess the data from the system thinking test. In this study, data analysis using the non-parametric Mann-Whitney U test was conducted to understand whether there was an influence between the control experiment's pretest and the control experiment's post-test. The Wilcoxon test was conducted to determine whether there was an increase between the control class pretest and post-test. The effect size test was conducted to understand the magnitude of the effect of the independent variable on the dependent variable in a study (Field, 2009).

RESULTS AND DISCUSSION

This research implements project learning with an integrated approach to STEM on alternative energy materials. (Science) students are allowed to understand and identify problems related to environmental phenomena and develop the ability to formulate solutions. Furthermore, technology students conduct further research by reading ebooks and exploring other sources to design projects that can be a solution. Implementation (engineering) students are involved in designing product experiments based on their research results. They have the opportunity to apply engineering concepts and design innovative solutions. Finally, (mathematical) students use math skills to calculate the success rate of the project that has been created.

Table 3 Descriptive statistics test results

Group	N	Pretest				Post-test			
		Mean	Std	Mdn	IQR	Mean	Std	Mdn	IQR
Experiment	34	9.40	3.34	8.50	6.00	14.59	3.48	14.00	4.00
Control	34	13.91	6.05	13.00	11.00	13.91	4.17	14.00	3.00

Table 3 shows that the students' system thinking ability, pretest and post-test of experimental and control classes, falls into the low category, around 56%. Furthermore, the study showed increased system thinking scores in both groups after being given treatment. There was an increase in the experimental class. Therefore, an inferential statistical test is needed to determine whether this increase is statistically significant.

Data normality was performed before conducting hypothesis testing. The results of the normality test are presented in Table 4.

Table 4 Normality test results

System Thinking Ability	Group	Shapiro-Wilk Statistic	df	Sig.
Pretes	experiment	.926	34	.023
	control	.928	34	.027
postes	experiment	.943	34	.075
	control	.882	34	.002

In Table 4, the data is not normally distributed; therefore, the Mann-Whitney U test is used to see if there is a difference between the pretest scores in the control and experimental classes. The Mann-Whitney U test is also used for the post-test score. The results of the Mann-Whitney U test are shown in Table 5.

Table 5 Mann Whitney U hypothesis test result

System Thinking	Group	N	Mean Rank	Rank sum	U	P
Pretest	Control	34	26.76	910.00	315.00	.001
	Experiment	34	42.24	1436.00		
Posttest	Control	34	36.76	1250.00	501.00	.341
	Experiment	34	32.24	1096.00		

Table 5 shows that the results of Mann-Whitney U show a significant difference between the pretest score of systems thinking in the control and experimental classes. However, there is no significant difference between the post-test scores for systems thinking in the control and experimental classes. The results can be seen in Table 5. Therefore, in this case, according to Türk & Çam (2024), it is wrong to say that the changes that occurred in the class were only due to the treatment given. A Wilcoxon test was conducted to determine changes in improvement in the pretest and posttest of the control and experimental classes.

Table 6 Wilcoxon hypothesis test results

System Thinking	Group	N	Mean Rank	Rank sum	Z	P
Experiment	Pretest	34	17.61	475.00	-4.465	.000
	Posttest	34	5.13	20.50		
Control	Pretest	34	17.56	281.00	-.282	.778
	Postest	34	17.44	314.00		

Data Table 6 shows a statistically significant difference between the pretest and post-test scores in the experimental class ($z = 0.000$, $p<0.05$). At the same time, there is no statistically significant difference between the pretest and post-test scores in the control class ($z = 0.778$, $p > 0.05$), which does not support the statement about the pretest.

The effect size test was conducted to determine further improvement results. The results obtained for the experimental class amounted to $r = 0.54$. It shows that the improvement in the experimental class was in the large category at the system thinking level.

The median shows that the level of thinking ability in the experimental class has increased significantly with the post-test value (mdn = 14.00) compared to the pretest value (mdn = 8.50); $Z = 4.465$; $p <0.05$; $r = 0.54$. However, there was an increase in the category of students' system thinking ability in the low category of 56%. While the median results of system thinking ability in the control class did not show a significant increase with the post-test value (mdn = 14.00) compared to the pretest value (mdn = 13.00), $Z = -0.282$, $p > 0.05$, it is still in the basic category.

The results showed a significant increase in the system-thinking ability of experimental class students. Meanwhile, there was no improvement in the system-thinking ability of control class students. Some other findings from this study are that the systems thinking ability is still low, and the difference in ability at the beginning does not affect the final results of the two classes.

Utilizing a STEM-focused project-based learning model improves students' systems thinking abilities. It allows them to actively participate in the learning process, discover new information, and seek references about the project they are working on and how it is applied in everyday life. This finding supports Rahmania (2021), who found that PjBL-STEM learning can encourage the development of high-order thinking skills.

According to Bungsu and Rosadi (2021), improving system thinking skills can be influenced by two factors, namely internal factors and external factors. One of the internal factors is education. A good education can form a superior mindset (Hikmah, 2019). In this case, the method used in learning, namely PjBL STEM, is one of the internal factors because it provides a good education to improve system thinking skills, specifically pupils' different cognitive capacities and their degree of participation in activity learning (Assaraf & Orion, 2005). External factors that might improve systems thinking include friends. In classroom learning, friends greatly affect the quality of learning. With this learning model, students are more often in contact with or in discussion with friends than with educators. PjBL STEM learning strongly emphasizes aspects of cooperation in groups. Students solve problems with group discussions and make designs with their groupmates to arouse students' systems thinking skills.

There was a difference in the initial ability level between the two classes. An interesting finding from this study was that the difference had no impact on the final results. This suggests that other factors, such as the teaching method, the level of student engagement, or the learning approach applied, played an important role in shaping their final achievement. This finding reinforces the idea that learning that supports and accommodates different levels of ability can create an environment that stimulates collective development, overcomes initial disparities, and opens opportunities for shared success at the end of the learning process (Nurlaili & Hayati, 2022).

In the context of this study, students' systems thinking skills still show a relatively low level. This finding highlights the challenges of developing analytical skills and understanding concepts holistically. However, introducing learning strategies that focus on systems thinking indicators can be an initial step that can potentially improve these abilities. In addition, applying PjBL-STEM learning to Madrasah Aliyah students is one of the challenges in this study. The low value of students' system thinking in this study is thought to occur because learning in madrasahs prioritizes religious sciences such as fiqh, tafsir, and memorization of the Koran (Anwar & Nugroho, 2023). Further efforts are needed to create learning approaches that attract and motivate students to develop their systems thinking skills more effectively. Systems thinking skills are still not maximally practiced in schools in Indonesia.

Table 7 Level descriptive statistics test result

Description	Control						Experiment					
	Mean		Mdn		IQR		Mean		Mdn		IQR	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Level 1	3.47	3.86	4.00	4.00	3.00	1.00	2.28	3.85	3.00	4.00	2.00	2.00
Level 2	3.61	3.16	3.00	3.00	3.00	2.00	1.88	4.47	2.00	4.00	2.00	2.00
Level 3	2.94	2.38	2.00	2.00	4.00	2.00	0.29	1.88	1.50	1.00	2.00	1.00
Level 4	3.32	3.47	4.00	4.00	2.00	2.00	2.37	3.52	2.50	4.00	1.00	2.00

Table 7 shows that the control class's median pretest and post-test scores are not different. The median pretest and post-test scores increased for the experimental class at levels 1, 2, and 4. The lowest median score in the control and experimental classes was shown at level 3.

Descriptive statistical results improved at the pre-requirement, basic, and coherent expert levels. However, the intermediate level has decreased. This does not support the graded indicator that the expert level should be the most difficult. Causality is the ability to make generalizations from patterns formed by the system (Jalmo & Lengkana, 2023). The causality approach is included in the intermediate-level skills that students least master because systems thinking emphasizes the idea of interconnection. This is loaded into the application activity. Due to the limited tools, some students try, and others calculate the effectiveness. So, interconnection modeling has not been clearly illustrated in the minds of each student. This is supported by the results of research (Nuraeni & Aliyah, 2020) that showed recognition of causality is included in the category that students least master.

The following are the results of the students' work shown in Figure 1.

(a) (b)

Figure 1 (a) Student project result: automatic garden light and (b) Student project result: automatic garden light

Figures 1 and 2 show the product of student work from the learning that has been done, namely automatic garden lights based on solar panels. Integrating

STEM PjBl into learning in the experimental class includes reflection (problem identification), where students identify the impact of non-renewable energy and the phenomenon of renewable energy. This can generate an understanding of the concept of pre-requirement, namely the structure and role of components in the system at this stage, including the scientific approach. Research (gathering information) Students read several sources on the internet and conduct experimental activities. This activity can increase understanding of the interaction relationship between its components. This stage includes the technology, engineering, and math approaches. Discovery (designing and designing) students design automatic garden lights with solar panels, starting with cover design and circuit design.

Furthermore, students create a project that has been designed. This can increase understanding of the interaction between its components. This activity includes an engineering approach. Application (Trial) Students conduct trial activities for the projects they make and analyze the effectiveness of their tool projects. This process can increase students' knowledge about analyzing the modeling or concepts they have made (intermediate). This activity includes engineering and math approaches. Communication: at this stage, students present the products that have been made with the following provisions: conveying the background of the project, the concept relevant to the project with renewable energy, the steps of doing the project, the problems encountered when making and how to solve them, the components used, the uniqueness of the project, explaining the design, and how to measure performance. After that, students are given feedback from peers and educators, and then they redesign with the input obtained. This process can develop the ability to reflect on the results of the project that has been made (coherent expert).

Then, the results of each level of system thinking (1, 2, and 4) increased. In the control class, the four levels did not change. However, Level 3 in both the control and experimental classes is the lowest. This research uses multilevel indicators, namely pre-requirement, basic, intermediate, and coherent expert. In the experimental class, indicators at the pre-requirement, basic, and coherent expert levels increased. This is because the teaching in the experimental class was designed with innovative and interactive methods, providing opportunities for students to be more involved in learning. In addition, the carefully structured lessons were designed to meet learners' individual needs, ensuring that the material taught was relevant and easy to understand. Furthermore, research project activities can enrich their learning experience. Therefore, through this combination of efforts, the experimental class successfully improved academic achievement and developed systems thinking skills.

There was no change in the control class on all four indicators of pre-requirement, basic, intermediate, and coherent expert levels. One of the main factors may lie in the teaching method used in the control class. The method used in the control class was conventional learning. If the learning method does not change from before, this may result in consistent results and not show improvement. In addition, applied learning did not undergo the necessary adjustments to respond to the latest educational developments. Another possible factor is the level of student participation in learning activities. Therefore, the success of the control class in achieving change requires an in-depth evaluation of the teaching strategy and additional support to improve learning effectiveness.

This study shows that using project-based learning integrated with STEM improves students' systems thinking skills. Despite the success of STEM PjBL learning, this study has limitations. First, the number of students involved was limited to the upper secondary level, and there were limited participants. According to Creswell & Creswell (2018), the number of samples determines the generalization of the research results. Second, there are limitations on the material used. This study was conducted on renewable energy materials, especially solar energy. The researcher recommends that future studies do the same thing with different materials.

CONCLUSION

Using PjBL-STEM learning impacts improving students' systems thinking skills. PjBL-STEM learning allows students to be actively involved during the learning process. In addition, PjBL-STEM learning can foster a superior mindset. Although there was an increase in the ability to think systems in the experimental class, the ability to think systems was still in the low category both before and after treatment in the control and experimental classes. Therefore, the introduction of learning strategies that focus on system thinking indicators can be an initial step that has the potential to improve these abilities and be carried out continuously.

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