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EFFECT OF PBL INTEGRATED WITH STEM ON STUDENTS' SYSTEMS THINKING IN ALTERNATIVE ENERGY

Yuli Yani Permata Sakti[1], Anggreini[1], I Wayan Distrik[1], Viyanti[1]
[1]Department of Physics Education, Universitas Lampung, Indonesia
Corresponding author email: anggreini@fkip.unila.ac.id

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Abstract :
Systems thinking is one of the essential abilities needed to address global challenges in the 21st century because it enables students to understand the relationships among components and the dynamics within a system comprehensively. However, preliminary study results showed that students' systems thinking ability had not been measured in physics learning, particularly on the topic of alternative energy. Therefore, the implementation of the Problem Based Learning (PBL) model with a STEM approach is expected to support the development of students' systems thinking ability. This study aimed to determine the effect of the PBL model with a STEM approach on students' systems thinking ability regarding the topic of alternative energy. The study employed a quasi-experimental method using a non-equivalent control group pretest-posttest design. The sample was selected through purposive sampling, involving class X1 as the experimental class and class X3 as the control class at SMAN 1 OKU. Data were collected using pretest and posttest instruments consisting of 12 two-tier multiple-choice questions. The results showed that the experimental class achieved a higher average n-gain score (0.42, moderate category) compared to the control class (0.29, low category). Furthermore, the independent samples t-test result showed a significance value of 0.004 < 0.05, with an effect size value of 0.337 in the large category. These findings indicate that the implementation of the PBL model with a STEM approach significantly affects students' systems thinking ability on the topic of alternative energy.

Keywords: Problem Based Learning, STEM, Systems Thinking

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INTRODUCTION

Systems thinking ability is one of the important abilities that students need to possess in the 21st century because it helps students understand complex real-world problems comprehensively (Nuraeni et al., 2020). This ability enables students to identify relationships among components within a system, analyze cause-and-effect relationships, and predict the impacts resulting from a phenomenon (Purwanti & Kusumawati, 2021). One of the topics closely related to complex real-world problems is alternative energy. Alternative energy serves as a solution to reduce dependence on fossil energy sources such as petroleum, coal, and natural gas (IRENA, 2023). The transition toward alternative energy has become increasingly urgent because fossil energy sources are limited and are major contributors to greenhouse

gas emissions, which can lead to climate change, environmental pollution, and negative impacts on human health and ecosystem balance (IEA, 2022). Therefore, alternative energy learning is expected to equip students with the ability to analyze energy availability problems and design solutions through the utilization of alternative energy sources (Kemendikdasmen, 2025). This learning objective is also aligned with the role of education in developing environmental awareness as the foundation of sustainable development (UNESCO, 2020). Consequently, students are expected not only to understand energy concepts but also to analyze the relationships and interactions among components within a system comprehensively (Matitaputty et al., 2022).

Based on the results of a preliminary study conducted at SMAN 1 OKU, learning on the topic of alternative energy still tends to focus on delivering theoretical concepts without relating them to real-life problems. As a result, students are less accustomed to connecting the concepts they learn with real phenomena. The questionnaire results showed that most students still experienced difficulties in explaining system components, identifying relationships among system components, organizing relationship patterns within a system, and predicting the impacts of an action In addition, students were not yet accustomed to integrating aspects of science, technology, engineering, and mathematics in physics learning or to solving real-world problems related to everyday life. This condition aligns with findings in local educational contexts where physics instruction often faces challenges in training analytical reasoning, higher-order thinking skills, and contextual problem-solving (Viyanti et al., 2025). These findings indicate that the learning process has not fully facilitated students in developing systems thinking ability. Therefore, a learning model is needed that can facilitate students in developing systems thinking ability through contextual problem-solving activities (Shofatun et al., 2024).

SMAN 1 OKU has environmental potential that can be utilized as a contextual learning resource for alternative energy, particularly hydroelectric power generation. The school is located near the Ogan River, which has a relatively stable water flow throughout the year. However, real problems remain in the surrounding river area, including limited street lighting on bridges that may affect public safety and comfort. This phenomenon provides a relevant context for problem-based learning, in which students can analyze the potential of water energy and design a simple *waterwheel-powered light* prototype. Hands-on exploration through hydro-based renewable energy kits and simple prototypes has been shown to effectively bridge theoretical energy concepts with concrete, measurable physical phenomena (Nur & Adawiyah, 2026). Through these activities, students are expected to develop systems thinking ability by identifying system components, analyzing relationships among components, organizing interactions within the system, and predicting the impacts of changes in the system (Assaraf & Orion, 2005).

The PBL model places real-world problems as the main trigger in the learning process (Aprina et al., 2024). In its implementation, the PBL model requires students to work collaboratively in groups to discuss problems, identify learning needs, gather information from various sources, and formulate solutions to the given problems (Kartini et al., 2022). The implementation of the PBL model on the topic of alternative energy can provide meaningful learning experiences because students not only understand physics concepts theoretically but also understand the relationships among components within an energy system through real-world problems related to everyday life (Cole et al., 2025). Furthermore, PBL on alternative energy topics has been proven effective in optimizing students' analytical skills and supporting ESD by engaging students in real-world energy challenges (Fitria et al., 2025). In the problem-solving process, students need to integrate various aspects of science, technology, engineering, and mathematics. Therefore, PBL is relevant to be integrated with a STEM approach to provide students with opportunities to develop solutions by applying knowledge and skills across these disciplines (English, 2023). Previous studies in physics education have shown that integrating STEM disciplines into Problem-Based Learning syntax provides students with structured environments to solve real-world problems, significantly boosting their critical thinking and analytical reasoning skills (Yogi et al., 2021). Furthermore, the implementation of PBL integrated with a STEM approach has the potential to strengthen students' systems thinking ability because students are engaged in analyzing complex problems, identifying relationships among system components, and designing solutions to real-world problems (Saputri & Suryadi, 2024).

Previous studies have shown that STEM-integrated learning can support the development of students' systems thinking ability across different learning contexts. Rahayu et al (2022) reported an improvement in students' systems thinking through PBL integrated with STEM and a flipped classroom

on the topic of work and energy, while Saputri & Suryadi (2024) found a positive effect of PBL-STEM on students' systems thinking in global warming learning. In the context of energy-related learning, Kurniawan et al (2024) investigated students' systems thinking through PjBL-STEM integrated with ESD on renewable energy, while Habibah et al. examined the effect of PjBL-STEM learning on students' systems thinking skills on alternative energy materials. These studies provide evidence that both PBL and PjBL-STEM learning can support students' systems thinking ability. However, while previous studies have examined PBL STEM in different contexts and PjBL-STEM on alternative or renewable energy topics, evidence regarding the implementation of PBL integrated with a STEM approach specifically on alternative energy to develop students' systems thinking ability remains limited. Therefore, further investigation is needed to examine the effect of PBL integrated with STEM on students' systems thinking ability in alternative energy learning.

Building on these previous studies, the present study applies PBL integrated with a STEM approach to alternative energy learning using a contextual local problem related to the utilization of water energy near the Ogan River. The present study differs from the reviewed studies by applying PBL integrated with STEM specifically to alternative energy, rather than using PBL-STEM on work and energy or global warming or PjBL-STEM on renewable and alternative energy. In this study, students analyze a contextual problem related to limited street lighting and design a simple *waterwheel-powered light* prototype as a potential solution by integrating science, technology, engineering, and mathematics. The contribution of this study is to provide empirical evidence regarding the effect of PBL integrated with a STEM approach on students' systems thinking ability in alternative energy learning and to demonstrate how a local energy problem can serve as a contextual resource for physics learning. Therefore, this study aims to determine the effect of PBL integrated with a STEM approach on students' systems thinking ability in the topic of alternative energy.

RESEARCH METHOD

Research Design

This study employed a quantitative research method with a quasi-experimental design using a *nonequivalent control group pretest-posttest design*. This design was selected because the study involved intact classes that could not be randomly assigned at the individual level (Creswell & Creswell, 2018; Creswell & Clark, 2023). The study involved two groups: an experimental class that received learning using the *Problem-Based Learning* (PBL) model integrated with the STEM approach and a control class that received learning using the *Direct Instruction* (DI) model with a scientific approach. The research design is presented in Table 1.

Table 1. Research Design

Group	Pretest	Treatment	Posttest
Experimental	O_1	PBL integrated with STEM approach	O_2
Control	O_3	Direct Instruction with scientific approach	O_4

Table 1 illustrates the nonequivalent control group pretest-posttest design used in this study. Both groups were assessed before and after the intervention to examine changes in students' systems thinking ability. The experimental group received PBL integrated with a STEM approach, whereas the control group received Direct Instruction with a scientific approach. O_1 and O_3 represent the pretest measurements, while O_2 and O_4 represent the corresponding posttest measurements for the experimental and control groups, respectively.

Research Target/Subject

The population of this study consisted of all tenth-grade students at SMAN 1 OKU during the second semester of the 2025/2026 academic year. The participants were selected using *purposive sampling* based on relatively similar initial academic abilities and consideration of the school's instructional conditions. Purposive sampling allows researchers to select participants based on characteristics relevant to the purpose of the study (Creswell & Creswell, 2018). Class X.1 was assigned as the experimental class, while Class X.3 served as the control class, with 36 students in each class.

The research instrument was tested separately from the main study on 37 students of class XI.1 at SMAN 1 OKU during the second semester of the 2025/2026 academic year. The instrument trial was conducted before the main study to evaluate the empirical quality of the test items, including item validity, reliability, difficulty level, and discrimination index.

Research Procedure

This study was conducted in three stages, namely the preparation stage, the implementation stage, and the final stage. The following is an explanation of each stage.

1. Preparation Stage

The activities conducted during the preparation stage were as follows:

a. Obtaining permission from the school to conduct research at SMAN 1 OKU;
b. Conducting preliminary studies through interviews and questionnaires;
c. Determining research sample classes and scheduling research activities;
d. conducting a literature review related to the PBL model, STEM approach, systems thinking ability, and alternative energy;
e. preparing learning materials, lesson plans, worksheets, and research instruments; and
f. conducting an empirical trial of the research instrument to determine its validity, reliability, difficulty level, and discrimination index.

The preparation of the learning intervention was based on the PBL syntax proposed by Arends (2012) and the STEM approach proposed by Bybee (2013). The systems thinking instrument was developed based on the indicators proposed by Assaraf and Orion (2005). The two-tier test format was adopted to assess both students' selected answers and the scientific reasoning underlying those answers (Lengkong et al., 2021).

2. Implementation Stage

The intervention was conducted from 24 February to 6 March 2026. Each class received four treatment sessions. The experimental class received learning using the PBL model integrated with the STEM approach, whereas the control class received learning using the DI model with a scientific approach. Each treatment session consisted of three lesson periods (JP), with each JP lasting 30 minutes. Thus, each treatment session consisted of 90 minutes of scheduled learning time. The detailed sequence and duration of the research activities are presented in Table 2.

Table 2. Research Implementation Schedule Eksperimental Class

Date	Activity	Learning Stage	Time
24/02/2026	Pretest	Initial systems thinking assessment	09:15–09:45
25/02/2026	Treatment 1	PBL Phase 1: Orienting students to the problem and Phase 2: Organizing students for study	10:40–12:10
26/02/2026	Treatment 2	PBL Phase 3: Assisting independent and group investigation	08:15–09:45
04/03/2026	Treatment 3	PBL Phase 4: Developing and presenting a *waterwheel-powered light* prototype	10:40–12:10
05/03/2026	Treatment 4	PBL Phase 5: Analyzing and evaluating the problem-solving process	08:15–09:45
06/03/2026	Posttest	Final systems thinking assessment	10:10–10:40

The pretest was administered before the first treatment. The four treatment sessions were then conducted according to the research schedule. After completion of the fourth treatment session, the posttest was administered to both groups.

3. Final Stage

The final stage consisted of scoring and organizing the pretest and posttest data, conducting statistical analyses, interpreting the results, and drawing conclusions regarding the effect of the PBL model integrated with the STEM approach on students' systems thinking ability.

Instruments, and Data Collection Techniques

Students' systems thinking ability was measured using a two-tier multiple-choice test. The initial instrument consisted of 16 items developed based on the four systems thinking indicators. Each

item consisted of two tiers, in which the first tier required students to select an answer to a given problem and the second tier required students to select the scientific reason supporting their answer. The two-tier format enables assessment of students' answers together with the reasoning underlying those answers.

Instrument Specification

The initial instrument consisted of 16 items, with four items representing each systems thinking indicator. After empirical testing, four invalid items were removed, resulting in a final instrument consisting of 12 valid items. The distribution of the initial and final items across the four systems thinking indicators is presented in Table 3.

Table 3. Initial and Final Specification of the Systems Thinking Instrument

No.	Systems Thinking Indicator	Initial Item Numbers	Final Items Number
1	Identifying the components of a system and processes within the system	2, 3, 4, 5	2, 3, 4
2	Identifying relationships among system components	1, 7, 12, 8	1, 6, 9
3	Organizing system components and processes within a framework of relationships	6, 15, 16, 9	5, 11, 12
4	Thinking temporally: retrospection and prediction	10, 11, 13, 14	7, 8, 10
Total		16	12

The four invalid items were items 2, 8, 9, and 14, so they were excluded from the final instrument. The remaining 12 valid items were retained and renumbered as the final instrument.

Instrument Validity and Reliability

Item Validity

The initial 16-item instrument was empirically tested on 37 students of class XI.1 at SMAN 1 OKU. Item validity was evaluated by comparing the calculated correlation coefficient (*r* calculated) with the critical value (*r* table). With 37 respondents, the *r*table value used in the analysis was 0.325, and an item was considered valid when *r* calculated > *r* table.

Table 4. Results of the Validity Test of the Initial 16-Item Instrument

Item	r calculated	r table	Decision
1	0.700	0.325	Valid
2	0.278	0.325	Invalid
3	0.394	0.325	Valid
4	0.348	0.325	Valid
5	0.455	0.325	Valid
6	0.445	0.325	Valid
7	0.650	0.325	Valid
8	0.090	0.325	Invalid
9	0.014	0.325	Invalid
10	0.544	0.325	Valid
11	0.543	0.325	Valid
12	0.731	0.325	Valid
13	0.717	0.325	Valid
14	0.121	0.325	Invalid
15	0.729	0.325	Valid
16	0.692	0.325	Valid

The validity analysis showed that 12 of the 16 initial items were valid, whereas items 2, 8, 9, and 14 were invalid because their *r*calculated values were lower than 0.325. Therefore, these four items were excluded from the final instrument.

Instrument Reliability

The reliability of the instrument was assessed using Cronbach's alpha. The initial 16-item instrument produced a Cronbach's alpha coefficient of 0.796, while the reliability analysis conducted after excluding the four invalid items produced a Cronbach's alpha coefficient of 0.832 for the final 12-item instrument. The reliability analysis indicates that the final 12-item instrument demonstrated higher internal consistency than the initial 16-item instrument. The interpretation of Cronbach's alpha was based on (Field, 2009; Maric et al., 2023; Zakariya, 2022).

Table 5. Reliability Test of the Instrument

Instrument	Number of Items	Cronbach's Alpha	Interpretation
Initial instrument	16	0.796	Acceptable
Final instrument	12	0.832	Good

Table 5 shows that the final 12-item instrument achieved good internal consistency, with a Cronbach's alpha of 0.832, exceeding the initial value of 0.796 obtained from the 16-item instrument. Thus, the final instrument was considered sufficiently reliable for subsequent analysis.

Item Difficulty

The difficulty level was analyzed for the 12 items retained in the final instrument. The difficulty index (p) represents the proportion of students who successfully answered an item, with values approaching 1 indicating easier items and values approaching 0 indicating more difficult items. Items with a difficulty index close to 0.50 provide greater opportunity for differentiating students' abilities (Crocker & Alglna, 2006).

Table 6. Results of the Item Difficulty Analysis

Item	Mean	Maximum	Difficulty Index (p)	Category
1	1.68	3	0.56	Moderate
2	2.68	3	0.89	Very easy
3	2.92	3	0.97	Very easy
4	2.16	3	0.72	Easy
5	2.51	3	0.84	Very easy
6	1.86	3	0.62	Easy
7	2.38	3	0.79	Easy
8	2.86	3	0.95	Very easy
9	2.19	3	0.73	Easy
10	2.35	3	0.78	Easy
11	2.03	3	0.68	Easy
12	2.43	3	0.81	Very easy

Table 6 indicates that the difficulty indices ranged from 0.56 to 0.97, representing moderate to very easy items. Most items were categorized as easy or very easy, while Item 1 showed the lowest difficulty index (0.56) and therefore provided the greatest relative opportunity for differentiating students' abilities.

Item Discrimination

The discrimination of the 12 retained items was determined using the *corrected item-total correlation*. The discrimination index indicates the extent to which an item differentiates students with relatively higher and lower overall test performance. The interpretation criteria followed Crocker and Algina (2006).

Table 7. Results of the Item Discrimination Analysis

Item	Corrected Item-Total Correlation	Category
1	0.59	Very good
2	0.32	Good
3	0.30	Good
4	0.33	Good
5	0.34	Good

Item	Corrected Item-Total Correlation	Category
6	0.53	Very good
7	0.42	Very good
8	0.48	Very good
9	0.64	Very good
10	0.63	Very good
11	0.65	Very good
12	0.61	Very good

The results showed that four items had good discrimination and eight items had very good discrimination. Therefore, all 12 retained items met the predetermined discrimination criteria. Based on the results of the validity, reliability, difficulty, and discrimination analyses, the 12-item final instrument was retained for use in the main study.

Data Analysis Technique

The data analysis technique used in this study was inferential quantitative analysis. The collected data were analyzed using IBM SPSS Statistics version 25.0 software. The analyses conducted included *N-gain*, normality, and homogeneity tests. Furthermore, hypothesis testing was performed using an *independent sample t-test* to determine differences between the experimental and control classes. An *effect size* analysis was conducted to determine the magnitude of the effect of the PBL model integrated with the STEM approach on students' systems thinking ability. In addition, an ANCOVA test was performed to strengthen the evidence that the differences in students' systems thinking ability were influenced by the treatment after controlling for students' initial ability.

RESULTS AND DISCUSSION

This study investigated the effect of the *Problem-Based Learning* (PBL) model integrated with the STEM approach on students' systems thinking ability in alternative-energy learning. The learning activities were designed around a contextual problem concerning limited street lighting and dependence on fossil energy sources. Students investigated the problem, analyzed energy concepts and energy conversion, and developed a simple *waterwheel-powered light* prototype as an alternative-energy solution. The integration of science, technology, engineering, and mathematics provided students with opportunities to examine the problem from interconnected perspectives rather than understanding the concepts separately (Smith et al., 2022). Based on the four indicators of systems thinking ability proposed by Assaraf and Orion (2005). The pretest and posttest results of students' systems thinking ability in the experimental and control classes are presented in Table 9.

Table 8. Pretestt and Postttest

Statistical Parameter	Kelas			
	Eksperimen		Kontrol	
	Pretest	*Posttest*	*Pretest*	*Posttest*
(1)	(2)	(3)	(4)	(5)
Number of students (N)	36	36	36	36
Lowest score	17	44	17	28
Highest score	69	86	64	75
Mean score	39,89	66,28	35,04	54,24

Table 9 shows that both the experimental and control classes experienced an increase in students' systems thinking ability after the learning process. However, the increase in the experimental class was greater than that in the control class. The mean score of the experimental class increased from 39.89 in the pretest to 66.28 in the posttest, whereas the control class increased from 35.04 to 54.24. The greater increase in the experimental class indicates that students who participated in PBL integrated with STEM demonstrated greater improvement in systems thinking ability than students who received Direct Instruction with a scientific approach.

The greater improvement in the experimental class indicates that PBL integrated with STEM provided learning experiences that were more closely aligned with the cognitive processes involved in

systems thinking. Systems thinking requires students not only to recognize individual components but also to understand relationships among components, organize system processes, and consider changes over time (Assaraf & Orion, 2005). These processes were repeatedly encountered during the investigation, prototype development, testing, and evaluation activities in the experimental class. The improvement can be explained by the problem-centered nature of PBL. PBL encourages students to investigate contextual problems, analyze information, collaborate with peers, and develop solutions rather than simply receive information from the teacher (Ayu et al., 2024). PBL has also been reported to facilitate students' problem-solving and analytical abilities through contextual learning activities (Aprina et al., 2024). These characteristics are relevant to systems thinking because students must examine a problem as an interconnected system rather than as a collection of independent concepts.

In this study, the contextual problem required students to examine the relationship between water as an energy source, waterwheel movement, energy conversion, electricity generation, and lighting performance. This relationship required students to connect several components into a meaningful system. The process therefore provided opportunities for students to construct an understanding of how changes in one component could influence other components. The STEM approach further strengthened this process by requiring students to integrate knowledge from several disciplines when solving the same problem. The science component enabled students to understand energy and energy conversion, while the technology component supported information searching and the use of digital learning resources (Smith et al., 2022). The engineering component required students to design and construct the prototype, while mathematics was used to support quantitative analysis of the prototype's performance (Smith et al., 2022). The integration of these components allowed students to connect abstract physics concepts with a concrete energy system. STEM-integrated PBL has been reported to facilitate students' systematic understanding of relationships among concepts through problem investigation (Rahayu et al., 2022). STEM learning can also support students in understanding relationships among components within a system through investigation and problem-solving activities (Habibah et al., 2024).

Therefore, the greater improvement in the experimental class was not merely related to students being more active during the learning process. Rather, the learning activities provided repeated opportunities to engage in reasoning processes that correspond to the dimensions of systems thinking. Students identified components, examined relationships, organized system processes, tested the system, and evaluated possible changes within the system (Assaraf & Orion, 2005). Before hypothesis testing, normality and homogeneity tests were conducted to determine whether the data met the assumptions for subsequent statistical analysis.

Table 9. Results of Normality and Homogeneity Tests

Test	Sig.	Interpretation
Normality test	>0.05	Normal
Homogeneity test	0.240	Homogeneous

The results of the normality test using the *Shapiro-Wilk* test showed that the pretest, posttest, and *N*-gain data had significance values greater than 0.05, indicating that the data were normally distributed. The homogeneity test resulted in a significance value of 0.240 (>0.05), indicating that the variances between groups were homogeneous. Therefore, the data met the assumptions required for the subsequent hypothesis testing.

Table 10. Results of Independent Sample T-Test and Effect Size

Variable	Experimental	Control	Sig. (2-tailed)	Effect size
N-gain	0.42	0.29	0.004	0.337

Table 11 shows that the experimental class obtained a higher *N-gain* value than the control class. The experimental class achieved an average *N-gain* of 0.42 in the moderate category, whereas the control class obtained an average *N-gain* of 0.29 in the low category. The *independent sample t-test* result showed a significance value of 0.004 (<0.05), indicating that there was a significant effect of implementing the PBL model integrated with the STEM approach on students' systems thinking ability.

To strengthen the findings, an ANCOVA test was also conducted. The ANCOVA results showed a significant effect of the treatment on students' posttest systems thinking scores after

controlling for pretest scores ($p < 0.001$), with a partial eta squared value of 0.337. The improvement in systems thinking ability was not uniform across the four indicators. Figure 1 presents the average scores of the systems thinking indicators in the experimental and control classes.

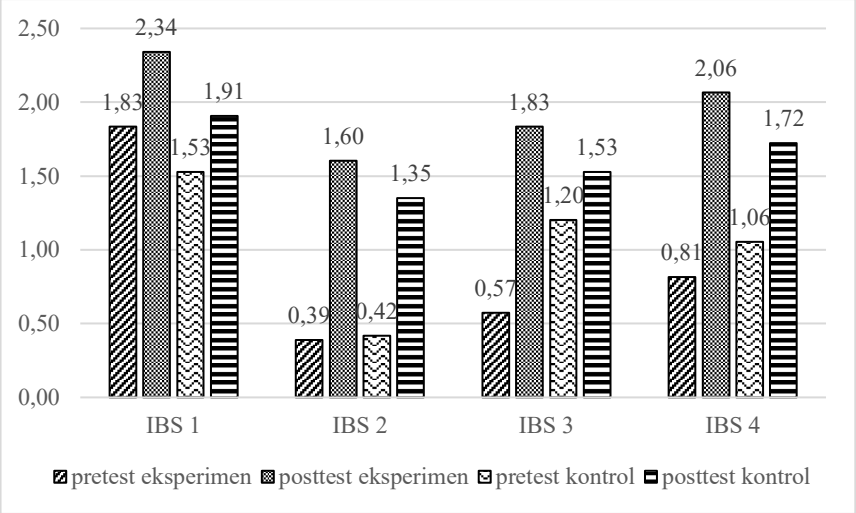

Figure 1. Average scores of systems thinking indicators

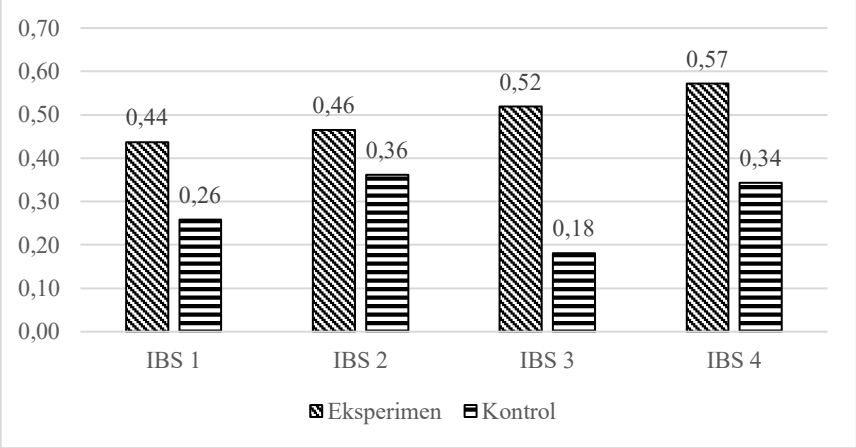

Figure 2. N-gain of systems thinking indicators

Figure 1 and 2, shows that all four systems thinking indicators improved in both classes, although the experimental class demonstrated greater improvement. The highest posttest score in the experimental class was obtained for *identify the components of a system and processes within the system* (IBS 1), with a score of 2.34, whereas the lowest score was obtained for *identify relationships among the system's components* (IBS 2), with a score of 1.60.

The higher IBS 1 score also suggests that concrete and observable learning experiences may have helped students develop an initial representation of the alternative-energy system. Students were able to connect the physical components observed during prototype construction with the concepts discussed during learning. STEM activities involving design and problem solving can support students in connecting scientific concepts with physical components and processes (Serevina et al., 2024). Thus, the direct interaction with the prototype likely contributed to students' ability to identify the components and processes of the energy system.

In contrast, IBS 2 obtained the lowest posttest score among the four indicators. This indicator requires students to understand how one component is related to and influences another component within a system. Identifying relationships among system components requires more complex reasoning because students must move beyond recognizing individual elements and explain their interactions (Assaraf & Orion, 2005). In the alternative-energy context, students needed to understand how water flow influenced waterwheel movement, how the movement was converted into electrical energy, and

how the resulting energy affected the lighting output. The lower achievement on IBS 2 therefore suggests that relational reasoning remained a challenge for students even after participating in the PBL-STEM intervention. This finding is important because systems thinking involves a progression from identifying system elements toward understanding the relationships and interactions connecting those elements (Assaraf & Orion, 2005). Students may recognize that water, a waterwheel, a generator, and a lamp are components of the system without fully understanding the causal relationships among them. Consequently, future PBL-STEM activities should provide more explicit opportunities for students to construct causal diagrams, explain cause-and-effect relationships, and predict the effects of changes in one component on other components.

The third indicator, *organize the systems' components and processes within a framework of relationships*, was developed through activities involving prototype design, construction, and testing. Students were required to arrange different components into a functioning alternative-energy system. STEM learning involving design and problem-solving activities can support students' understanding of relationships among components and processes (Serevina et al., 2024). The engineering design process therefore provided students with an opportunity to transform their understanding of individual components into an understanding of how the components operate together as a system.

The fourth indicator, *thinking temporally: retrospection and prediction*, was supported through testing, evaluation, and reflection activities. Students reviewed the processes they had completed, evaluated the performance of the prototype, and considered possible improvements and future applications of alternative-energy solutions. Temporal thinking involves the ability to consider changes in a system by relating past and present conditions and predicting possible future developments (Assaraf & Orion, 2005). PBL integrated with STEM can support students in understanding cause-and-effect relationships and changes within a system through problem-solving activities (Saputri & Suryadi, 2024).

The findings showed that PBL integrated with STEM produced greater improvement in students' systems thinking ability than Direct Instruction with a scientific approach. The experimental class obtained a higher mean *N*-gain (0.42) than the control class (0.29), and the independent-samples *t*-test showed a significant difference ($p = 0.004$). The ANCOVA result also confirmed a significant treatment effect after controlling for students' initial ability ($p < 0.001$; partial eta squared = 0.337). This improvement can be explained by PBL activities that require students to investigate contextual problems, analyze information, and develop solutions, thereby supporting problem-solving and analytical abilities (Aprina et al., 2024). The STEM approach further requires students to integrate science, technology, engineering, and mathematics when solving authentic problems, providing opportunities to understand interconnected concepts and processes (Smith et al., 2022).

The improvement was also related to the characteristics of systems thinking, which requires students to identify system components, understand relationships, organize processes, and consider changes within an interconnected system (Assaraf & Orion, 2005). The alternative-energy context provided an authentic system involving energy sources, energy conversion, technological components, and system output. STEM-integrated PBL can facilitate systematic understanding of relationships among concepts through problem investigation (Rahayu et al., 2022). The *waterwheel-powered light* project further required students to connect physics concepts with prototype design, testing, and system performance, allowing them to understand how individual components interact to produce an overall output (Serevina et al., 2024).

Differences were observed among the systems thinking indicators, with IBS 1 (*identifying system components and processes*) showing the highest achievement and IBS 2 (*identifying relationships among system components*) showing the lowest achievement in the experimental class. This finding suggests that students may find it easier to recognize system components than to explain relationships among those components. Systems thinking develops progressively from recognizing system elements toward understanding relationships and organizing interactions within a system (Assaraf & Orion, 2005). This finding is consistent with previous research showing that PBL and STEM support problem-solving, analytical thinking, and systematic understanding (Aprina et al., 2024). However, the present study extends previous research by specifically examining four systems thinking dimensions in alternative-energy physics learning, providing evidence that PBL-STEM can support systems thinking beyond general higher-order thinking outcomes.

The findings have theoretical and practical implications for physics education. Theoretically, the results support the view that systems thinking can be developed through learning activities requiring students to identify components, analyze relationships, organize processes, and consider changes within a system (Assaraf & Orion, 2005). Practically, teachers can use PBL integrated with STEM to connect alternative-energy concepts with authentic problems and engineering applications (Rahayu et al., 2022). The *waterwheel-powered light* project can serve as a simple example of integrating energy concepts, technology, engineering design, and mathematical analysis (Smith et al., 2022). However, additional scaffolding such as system diagrams, guiding questions, and causal analysis may be needed to strengthen students' relational reasoning, particularly for IBS 2.

This study has several limitations. The quasi-experimental design, purposive sampling, and involvement of only two classes from one school limit the generalizability of the findings. The intervention also consisted of only four treatment sessions and focused on alternative-energy learning, while the 12-item two-tier test may not fully capture the complexity of systems-thinking reasoning. Future studies should involve larger and more diverse samples, longer interventions, and complementary assessments such as open-ended questions, concept maps, interviews, or performance-based assessments. Overall, this study contributes empirical evidence that PBL integrated with STEM can improve specific dimensions of systems thinking in alternative-energy physics learning, while also highlighting the need for greater instructional attention to students' understanding of relationships among system components.

CONCLUSION

Based on the results and discussion, it can be concluded that the implementation of the PBL model integrated with the STEM approach significantly improved students' systems thinking ability on the topic of alternative energy. The experimental class obtained a higher average *N*-gain score (0.42) than the control class (0.29), indicating greater improvement in systems thinking ability following the intervention. The independent-samples *t*-test also showed a significant difference between the two classes ($p = 0.004$), while the ANCOVA result confirmed the significant effect of the treatment after controlling for students' initial ability. These findings indicate that PBL integrated with STEM can be considered an alternative learning approach for developing systems thinking through contextual problem solving, investigation, design, and evaluation activities. In practice, physics teachers are recommended to integrate authentic alternative-energy problems and simple STEM projects, such as waterwheel-powered light, while providing additional scaffolding to help students understand relationships among system components. Future research should involve larger and more diverse samples, longer intervention periods, and complementary assessment methods such as open-ended questions, concept maps, interviews, or performance-based assessments to examine systems thinking development more comprehensively.

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