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The effect of problem based learning STEM (PBL STEM) on students' systems thinking skills on global warming material

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ABSTRAK

This study explores the effect of PBL-STEM on students' systems thinking skills in global warming topics. This research is a quantitative study with a quasi-experimental design. This study was conducted in one of the public high schools in South Tangerang. The participants involved were 72 students. In the experimental class, students learned with PBL-STEM, and the control group used conventional learning. The system thinking instrument was developed using 24 tested multiple-choice questions with a reliability of 0.83. The results showed that PBL-STEM significantly affected students' systems thinking skills ($p < 0.05$). The experimental class students' systems thinking was higher than the control class' systems thinking. Furthermore, systems thinking skills in the experimental class increased, but the highest value was at level 1 with the essential difficulty; in the control class levels 1 and 2, there was a more significant increase. This study can be continued for future research investigating the effect of PBL STEM on systems thinking skills in different contexts.

Keywords: Global Warming, PBL STEM, Problem Based Learning, STEM Education, Systems Thinking.

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INTRODUCTION

The problem that arises in physics learning is the low activity in-class learning; this causes the learning outcomes obtained by students to be different from what is expected. In physics learning, students wait for the teacher to explain and then take notes without asking questions or expressing their opinions. Systems thinking is one way of approaching students who view problems as a whole so that they can organize thoughts with more directed decision-making and will change the system effectively (Richmond, 1994). System thinking will give birth to an idea that impacts a student's action or behavior, so the implication will form a person's habit of thinking by responding to a problem around them (Bungsu & Rosadi, 2021).

Problem-based learning has been proven to be effective. The problem based learning model requires students to instil scientific thinking (Nuraeni et al., 2020). Applying problem-based learning emphasizes several aspects: asking questions and explaining problems, developing models, designing and carrying out research, analyzing data, making explanations and designing solutions, obtaining information, and conveying information (Abdurrahman et al., 2019). Problem-based learning in STEM education is a learning model that involves contextualized problems to produce students who can apply problem skills (Alatas & Oktaviani, 2020). Many studies have revealed that to maximize STEM outcomes, a combination of teaching methods, teaching duration, and teaching orientation is required (Kurniati et al., 2022).

To achieve the desired research objectives, the application of Problem-based Learning in STEM Education (PBL-STEM) is carried out by forming several study groups so that students can get an experimental understanding of the facts. Students must find the concept or material studied based on the existing problems (Ramadhani et al., 2019). In addition, students are invited to have creativity and be able to master technology (Rehmat & Hartley, 2020). Nowadays, educating students must emphasize the skills and knowledge of making decisions to benefit students and others (Forrester, 1994). Then, using the context of system thinking can increase patterns of student awareness and thinking abilities (Haniyah & Hamdu, 2022). With that, students can decide on a problem by considering their interrelationships.

STEM education is essential to overcome the gap between the quality of graduates and industry needs. STEM education is not only taught in higher education; sharing parties encourage the primary level to apply STEM (Stohlmann et al., 2012) . STEM learning is different from the learning going on so far. STEM uses an interdisciplinary context in its process. Thus, students become familiar with problem-solving and reasoning , students respond more positively by improve some skills and are motivated to pursue careers in science, technology, engineering and maths (STEM). In addition with projects, students' scientific skills and engineering skills can be enhanced (Purwaningsih et al., 2020). By looking at the characteristics of PBL STEM learning, one can see the potential to develop students' systems thinking skills with PBL STEM. PBL STEM learning facilitates students' thinking systematically and helps them solve problems in everyday life. Many concepts in physics material focus on the facts of phenomena in everyday life, one of which is the material of global warming (Hrin et al., 2017).

Global warming material is one of the contexts contained in PISA (Programme for International Student Assessment), where the concept of the material discusses the symptoms of global warming and its impact on life so that students can propose ideas as solutions to the problem (Alatas & Fauziah, 2020). However, students still find it challenging to achieve this because the concept of global warming symptoms is still abstract, and most students assume that global warming occurs due to human activities (Habibah & Irawan, 2023). Through this topic, students are directed to apply solutions to the effects of global warming. This research explores the impact of problem based learning STEM on students' systems thinking skills on Global Warming Materials.

RESEARCH METHODS

This research was conducted in the even semester of the 2024/2025 school year at one of the public high schools in South Tangerang. This research uses a quantitative study with a quasi-experimental design that uses a pretest-posttest control group design. This study involved two classes, experimental and control. Both classes were given a pretest to measure students' initial systems thinking ability and a posttest to measure the final systems thinking ability. The intervention was carried out in the experimental class, and the control class did not receive treatment as a comparison to ensure the intervention was done so that no other factors caused changes in the experimental class. This research was conducted in class X SMA. Data collection was carried out for four meetings in March 2024. The participants in this study were X.1 class students, totaling 36 people as the experimental class, and X.3 class students, totaling 36 people as the control class.

This research is divided into three stages. The preparation stage involved preliminary studies, observations, interviews, and searching for literature related to PBL STEM learning and systems thinking. The second stage is the implementation stage in the control and experimental classes. Researchers gave a pretest to measure the initial ability of systems thinking. In the control class, researchers gave conventional learning treatment. In the experimental class, researchers provided learning treatment using PBL STEM, carried out in four meetings with detailed activities. In meeting one, students are divided into several groups. First, they are introduced to material about global warming, followed by carrying out activities according to worksheet instructions, starting from identifying problems, conducting discussions about activities to be carried out about solutions for making alternative energy, and finally given the task of determining the design of the tool to be made. Meeting 2 begins with carrying out activities per the worksheet, namely completing the tool's design and conducting experiments on the tools made. Meeting three students make improvements that need to be done to answer some questions in the discussion section. The fourth meeting began with preparing the presentation of student tool results. Then, each group made a presentation and was given feedback by their peers.

The research was conducted on the control class using conventional methods. This was done based on the results of interviews with teachers at the research site and adjusted to the teaching module prepared by the teacher (Nugroho,2023). Details of activities at the first meeting: The teacher introduces the topic using exciting pictures. Furthermore, students discuss in groups to stimulate thinking and improve initial abilities related to the subject to be studied. After that, students are allowed to explore the material through observation. The following group discussion discusses the results of student observations. The next step is for students to present the results of their observations, including theories, concepts, and their relation to the theory that has been taught(Yanti Herlanti, n.d.).

Furthermore, students are assigned to make a group project to apply the observations obtained. Students also explore additional aspects of the topic that has been discussed. The project meeting that students have made is presented, and then students ask questions about the project presented. Furthermore, the teacher and students evaluate the material learned (Arnold & Wade, 2015).

After that, the researcher gave a posttest to students in both control and experimental classes to determine the final ability of students' systems thinking. In the third stage, the results of the pretest and posttest were processed by the researcher by comparing the results of the instrument data before and after treatment to determine the difference in the improvement of students' systems thinking skills in global warming subjects in the control class and experimental class then the researcher will draw conclusions based on the analysis of the data obtained (Haniyah & Hamdu, 2022).

The test instrument used by researchers was adapted from Meilinda et al., (2018)and developed by experts (Boersma et al., 2011). The test instrument consists of 24 multiple-choice questions of four levels and 12 indicators.

Table 1. System Thinking Indicator

Level	Indicator	Item test number
Pre-Requirement	Identify the components and processes of a system	1,2
	Identify the relationship between structure and function/role in system components at an organisational level.	3
	Mapping the phenomenon/concept of renewable energy to help overcome the problem of global warming	4,5
Basic	Analyse the relationship of concepts at one level to those above or below it	6,7
	Organise system components, processes, and interactions between them in a system framework	8,9
	Identify feedback processes that occur in the system	10,11
Intermediate	Generalise the patterns formed by the system	12,13
	Design interaction patterns of system components that can be detected in a closed system.	14,15
	Create/develop a model that describes the position of all components in a closed system framework in 2D/3D both horizontally and vertically	16,17
Coheren Expert	Predict/retrospect the behaviour that arises from the system due to interactions between components in the system	18,19
	Predict / retrospect the impact that arises from interventions on the system using the model or pattern that has been designed	20
	Apply a new system pattern based on the results of prediction/retrospection	21,22,23,24

Three experts have validated the research instruments used. The instruments in this study were tested, including construct and content validation. The results of expert validation of some of the input given have been corrected by researchers so that the instrument is validated. Eighty participants also tested the instrument. The validation test used Pearson's product moment technique, which stated that 24 multiple-choice questions were declared valid, with the reliability test obtaining an Alpha Cronbach value of 0.83. A test instrument has valid content if the test material and materials represent the teaching material delivered or following the scientific material taught.

The data analysis used in this research uses quantitative studies by using descriptive and inferential statistics. Descriptive statistical analysis was carried out to describe the research data, which included the amount of data, maximum and minimum values, standard deviation, and average. Inferential analysis was carried out by first testing the normality and homogeneity of the data. Shapiro-Wilk normality test and homogeneity test with Levene's test ($p>0.05$). Data analysis uses parametric statistics because the research data is typically distributed. In this research, data analysis using the Independent Sample t-test parametric test was used to determine the significant difference in the average between the experimental class with the PBL STEM model and the control class using the conventional model (Christenson et al., 2014).

RESULTS AND DISCUSSION

This study implements a Problem Based Learning (PBL) approach integrated with Science, Technology, Engineering, and Mathematics (STEM) methodologies to address global warming. The research requires students to recognize and delineate environmental issues through scientific inquiry, enhancing their problem-solving skills. Participants are expected to engage with digital resources, such as ebooks, in the technological phase to devise actionable projects. Students collaboratively construct experimental prototypes that reflect their research findings during the engineering component, incorporating innovative solutions. In the final mathematical segment, learners employ quantitative methods to evaluate the efficacy of their completed projects. Based on the four levels of system thinking, the results of the analysis of students' system thinking tests with descriptive statistics are presented in Table 2 (Sari et al., 2022).

Table 2. Descriptive Statistics Test Result

Description	Experiment						Control					
	Mean		Median		IQR		Mean		Median		IQR	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Level 1	61,6	72,7	60,0	80,0	35,0	20,0	44,4	72,2	40,0	80,0	40,0	20,0
Level 2	45,0	61,6	50,0	66,0	33,0	33,0	35,7	54,7	33,0	50,0	34,0	16,0
Level 3	41,8	62,1	50.0	66,0	33,0	16,0	33,8	54,7	33,0	50,0	34,0	29,0
Level 4	47,8	67,8	42,0	71,0	15,0	25,0	34,1	50,3	28,0	57,0	40,0	33,0
All	49,5	61,6	50,0	62,0	16,0	24,0	39,3	54,8	35,0	56,0	32,0	20,0

Ideal Score 100

Table 2 shows the lowest median value for experimental and control classes at level 4 of the pretest section. The most considerable median value for experimental and control classes is shown at level 1 of the post-test section. This study uses multilevel indicators: prerequisites, essential experts, Intermediate, coherent. The system thinking indicators from level 1 to level 4 in the experimental class increased. This is because the teaching in the experimental class was designed with innovative and interactive methods to provide opportunities for students to be more involved in learning. In addition, structured and careful learning is designed to meet students' individual needs, ensuring that the material taught is relevant and easy to understand. This research can deepen their learning experience; therefore, the experimental class improved academic achievement and developed systems thinking skills. The average score of students' system thinking at each level is presented in Figure 1.

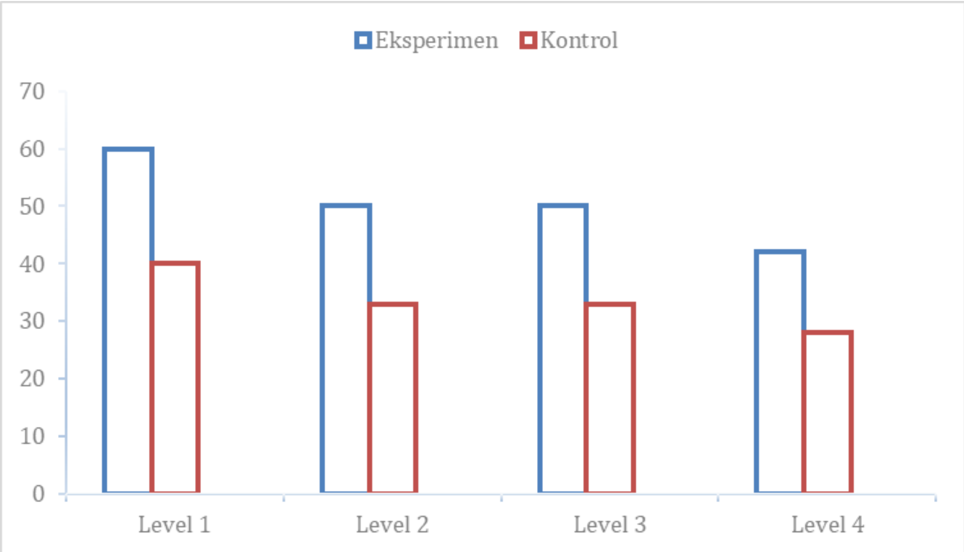

Figure 1. System Thinking Score Level

Figure 1 shows the system thinking score based on the indicator level. The highest score is at the prerequisite level. However, the intermediate to coherent level has decreased. This supports the assessment indicator that the intermediate to coherent level is the most challenging. Causality is the ability to generalize the patterns formed by the system (Jalmo & Lengakana, 2023). causality approach is included in the intermediate-level skills that students least master because systems thinking emphasizes the idea of interconnection .

Table 2 shows that students' system thinking skills, as seen from the pretest and posttest for the control and experimental classes, are still in the low category. Furthermore, this study shows increased system thinking scores in the experimental and control classes after treatment. To determine that this increase is statistically significant, inferential statistical tests are needed, such as testing the normality of the data before conducting hypothesis testing. The results of the normality test are presented in Table 4.

Table 3. Normality Test Result

System Thinking	Class	Shapiro Wilk		
		Statistic	df	Sig.
Posttest	Experiment	.979	36	.711
	Control	.947	36	.086

Table 3 shows that the data is usually distributed based on the Shapiro-Wilk normality test. If the significance value> 0.05, H0 is accepted, and H1 is rejected. The following analysis uses hypothesis testing with the independent sample T-test (Mala et al., 2021).

Table 4. Independent sample T-test

System Thinking	Class	N	Mean	Standar deviasi	Std Error Mean	t	df	Sig (2-Tailed)
Post Test	Experiment	36	61,64	15,00	0,495	24,784	0,35	0,000
	Control	36	54,83	12,3	0,622	22,049	0,35	0,000

Table 4 shows the average score between experimental class students (M = 61.64; Sd = 15.00) and control class (M = 54.83; Sd = 12.3). Based on the Independent Sample T-Test test analysis, the sig value (2-tailed) = 0.000 was obtained in the experimental and control classes. This shows that the null hypothesis (H0) is rejected, and the alternative hypothesis (Ha) is accepted. So, it can be said that there is a statistically significant difference between the average student system thinking in the experimental class and the control class.

Furthermore, the effect size test was carried out to determine the magnitude of the influence after treatment. The results obtained for the experimental class were 0.63, indicating that the increase in the experimental class was in the high category (moderate effect) at the system thinking level.

The results showed a significant increase in system thinking skills for the experimental and control classes. Some other findings from this study are that systems thinking skills are still in the low category. Utilizing STEM-focused projects can improve students' systems thinking skills. It allows them to participate actively 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 is supported by Newman (2005), who found that PBL STEM learning can encourage critical reasoning ability and higher-order thinking skills. According to Bungsu and Rosadi (2021), improving system thinking skills can be influenced by two factors, namely internal and external factors; one of the internal factors is education. Education with a superior mindset. In this case, the method used in learning, namely PBL STEM, is one of the internal factors because it can improve system thinking skills and student participation in learning activities.

This study's external factors of system thinking are friends; in-class learning, friends greatly influence class learning activities. With this learning model, students discuss more often with friends than with educators. PBL STEM emphasizes cooperation between groups. Students solve problems with group discussions and make project designs with their group friends. Interestingly, this study found that the initial treatment differed between classes.

In the context of this study, students' systems thinking skills still show a low category. This finding poses a challenge in developing students' analytical skills. However, introducing learning strategies focusing on systems thinking indicators can be a potential first step to improving these abilities. In addition, applying PBL STEM learning to high school students is one of the challenges in this study. The low value of students' systems thinking in this study is due to physics hours in class X only two hours a week, so many students need to remember the material taught in the previous meeting. Further efforts are required to create learning approaches that attract and motivate students to develop systems thinking skills that can be more effectively practiced in Indonesian schools.

The results table shows that the lowest median value for experimental and control classes is at level 4 of the pretest section. The most considerable median value for experimental and control classes is shown at level 1 of the post-test section. This study uses multilevel indicators: prerequisites, essential experts, Intermediate, and coherent. The system thinking indicators from level 1 to level 4 have increased in the experimental class. This is because the teaching in the experimental class was designed with innovative and interactive methods to provide opportunities for students to be more involved in learning. In addition, structured and careful learning is designed to meet students' individual needs, ensuring that the material taught is relevant and easy to understand. This research can deepen their learning experience; therefore, the experimental class improved academic achievement and developed system thinking skills .

In the control class, the coherent level got the lowest score. The system thinking indicator in the coherent section is the biggest challenge because, in this indicator, students predict/retrospect the impact that arises from the intervention on the system using a model or pattern that has been designed and is an indicator that shows the success of system thinking itself (Meilinda et al., 2018). One of the main factors is the teaching method used in the control class. The technique used in the control class is conventional learning. Another possible factor is the degree of involvement of student in learning activities; therefore, the success of the control class in achieving change requires an in-depth evaluation of learning strategies and additional support to improve learning effectiveness (Habron et al., 2012).

CONCLUSION

The integration of PBL STEM learning has an impact on improving students' systems thinking skills. PBL STEM learning requires students to be actively involved during the educational process. In addition, PBL STEM forms logical thinking skills and superior mindset. Although there was rise in proficiency to think systems in the experimental class, the ability to think systems was still in the low category at the coherent level, before and after treatment in the control and experimental class. Therefore, the introduction of learning strategies that focus on system thinking indicators can be a first step that has the potential to improve these abilities and be carried out in a sustainable manner.

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