The Implementation of STEM-PBL Learning to Enhance Students' Critical Thinking Skills

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Abstract *- This research is motivated by the importance of having 21st century skills, one of which is critical thinking skills. However, the facts show that students' critical thinking skills have not been fully realized optimally. Based on the results of preliminary studies and literature studies show that students' critical thinking skills are in the low to medium category. This research aims to enhance students' critical thinking skills through the implementation of STEM-PBL learning in the topic of temperature and heat. The research method used is quantitative research, specifically a pre-experimental design with the One Group Pretest-Posttest Design. This study involved 36 eleventh-grade students high school as the research sample. Data collection was done through a formative test based on critical thinking skill indicators. The research results indicate that the implementation of STEM-PBL learning can enhance students' critical thinking skills with an N-gain value of 0.5, categorized as medium. The highest N-gain was achieved in the indicator of basics clarification, while the lowest was in the indicator of advance clarification. Overall, the implementation of STEM-PBL learning has a positive impact on improving students' thinking skills.*

Keywords*: Critical Thinking Skill; PBL; STEM*

INTRODUCTION

As the 21st century progresses, technological advances made by humans are increasingly advanced and developed. In the era of Society 5.0, the main component in technological development is humans. To prepare quality and competitive human resources, strategic means are needed to facilitate it, one of which is education. Education in the era of Society 5.0 is an educational process that focuses on developing the ability of reason, knowledge and ethics of students accompanied by modern technological developments.

The Partnership for 21st Century Skills emphasizes that 21st century learning must include four competencies that must be possessed by students known as 4C competencies, namely critical thinking, creativity, communication, and collaboration. One of the competencies that learners must have in the 21st century is critical thinking skills. Critical thinking is part of higher order thinking skills. Ennis (2011) defines critical thinking skills as a logical and rational way of thinking in the decision-making process. Through critical thinking skills, students will be able to face and scrutinize all the problems they face. The urgency of critical thinking skills in 21st-century education requires learners to prepare themselves to face complex challenges and rapid technological developments in society. Future jobs will require individuals who can think critically, evaluate situations, and generate innovative solutions However, the facts show that students' critical thinking skills have not been fully realized optimally. This can be proven by the low ranking of Indonesian students in the PISA (Programms for International Student Assessment) survey results. Based on the results of PISA 2022 (OECD, 2023), Indonesia ranks 71st out of 81 countries in the reading literacy category, 70th out of 81 countries in the math literacy

category, and 67th out of 81 countries in the science literacy category. Indonesian students in 2022 produced relatively lower PISA scores in all categories. The questions tested by PISA on students are HOTS (Higher Order Thinking Skills) questions. The HOTS question model is a question that tests several skills that students must have in the 21st century, one of which is critical thinking skills. Based on this data, students in Indonesia still have critical thinking skills below the average.

Meanwhile, based on the results of a preliminary study at one of the high schools in Cimahi City, it was found that students' critical thinking skills were low. This is evidenced when students are faced with a problem, students tend to find it difficult to analyze and solve problems. In addition, during LKPD activities, students are usually asked to identify the relationship between existing variables, but students tend to look for answers via the internet rather than working independently. In line with this, research by Nainggolan, S. S., dkk. (2023) states that the average critical thinking skills in physics subjects are still relatively low because the teaching method used still uses the lecture method.

One of the learning alternatives that can facilitate learners to deal with technological developments and 21st century skills is learning that combines scientific practice and engineering practice, namely STEM. STEM education is a form of learning that integrates four disciplines: science, technology, engineering, and mathematics it is designed to develop 21st-century skills such as reasoning, problem-solving, critical thinking, creative and investigative skills, independent learning, technological literacy, teamwork and collaboration, and various other skills (Permanasari, et al.,2021; Zubaidah, S., 2019).

In addition, critical thinking skills can be trained through problem-based learning (Ariyatun, A., & Octavianelis, D. F., 2020). The Problem Based Learning (PBL) learning model is a learning model that uses real-world problems as a context for students to learn about critical thinking and problem-solving skills, as well as to gain essential knowledge and concepts from course material or subject matter (Adib, 2018). Through learning with the Problem Based Learning (PBL) model, it is hoped that students can develop critical thinking skills as a step to solve problems discussed in the material, and can draw conclusions based on their understanding (Arifah, N., et al., 2021).

Based on the previous explanation, critical thinking skills can be enhanced through STEM learning and Problem Based Learning Therefore, the researcher combines both of these learning approaches into one integrated teaching model, namely STEM-PBL learning. STEM-PBL learning is a learning model that confronts students with various problems in the context of science, technology, engineering, and mathematics. The STEM-PBL learning process is designed based on STEM practices, namely scientific practice and engineering practice and PBL stages. In implementing STEM practices, there is a framework or perspective that can be used and integrated in a learning model. Basically, the framework or perspective of the STEM approach has the same pattern as the stages of the PBL model so that both can be integrated into a learning model. STEM-PBL learning facilitates students in developing and practicing critical thinking skills through formulating problems and hypotheses, planning and conducting investigations, gathering information, analyzing and processing data, finding solutions, discussing and engaging in

arguments, and evaluating and communicating solutions.

Based on the explanation above, one of the alternatives that can be used to enhance students' critical thinking skills is the implementation of STEM-PBL learning This is in line with previous research conducted by other researchers, which stated that STEM learning integrated with the Problem Based Learning model is a suitable learning strategy to develop scientific attitudes, and encourages students to always be critical in finding concepts and linking their experiences with the material being studied, practice high-level thinking, gain experimental understanding from facts, provide comprehensive interpretations, learn to use ideas, utilize technology, and have creativity (Rohmah, H. N., et al., 2021; Putri, D. C., et al., 2020; Zulfawati, Z., et al., 2022; Febrianto, T., et al., 2020).

Based on the urgency of students' critical thinking skills and the need to link science, technology, engineering and mathematics in learning, it is necessary to apply STEM-PBL-based learning in physics learning. Therefore, the purpose of this study is to improve students' critical thinking skills through the application of STEM-PBL learning on temperature and heat material.

RESEARCH METHODS

The research method used in this study is a quantitative research method, namely pre-experimental, with a One Group Pretest-Posttest Design research design, as shown in Table 1.

Table 1. One Group Pretest-Posttest Design

Pretest	Treatment	Posttest
O_1	X	O_2

with :

O_1 : critical thinking pretest

O_2 : critical thinking posttest

X :treatment using STEM-PBL learning

The population in this study were all students of class XI in one of the public high schools in Cimahi city. While the sample of this study consisted of one class with a total of 36 students. The sample selection was selected by purposive sampling.

The implementation data of STEM-PBL learning is obtained based on the observations of supervisors or teachers during the learning process, which is then recorded in the observation sheet of learning implementation

Pretest activities are carried out before treatment to measure the initial ability of students in solving critical thinking skills questions in physics subjects. The treatment carried out is by applying STEM-PBL learning which consists of 5 stages, namely 1) Problem orientation, 2) Organizing students for learning, 3) Guide the investigation, 4) Developing and presenting work, 5) Analyze and evaluate problem-solving. At the problem orientation stage, the teacher stimulates students by displaying experimental simulations or illustrative videos about problems related to temperature and heat material. Learners ask questions and formulate problems based on what the teacher shows. At the stage of organizing students to learn, the teacher directs students to group and work on the LKPD distributed by the teacher. At the stage of guiding the investigation, students in groups collect data and information through experimental activities, process data into graphs, analyze the relationship between variables, and discuss to make conclusions to solve the problems in the LKPD. Then at the stage of developing and presenting work, students in groups communicate or present the results of solving the problems they have found. Furthermore, at the stage of analyzing and evaluating problem solving, the teacher provides opportunities for students to ask

questions, respond, or correct the results of the presentation group. Finally, the teacher provides reinforcement and conclusions from the learning carried out. After the treatment was carried out, a posttest is conducted to evaluate students' critical thinking skills.

The improvement of students' critical thinking skills is measured using a critical thinking skills-based test in the form of description questions. The questions were tested on students in the form of pretests and posttests. This test consists of 10 questions about temperature and heat, expansion, Azas Black, and heat transfer. Each question represents each indicator of critical thinking skills developed by Ennis (2011), namely basic clarification, bases for a decision, inference, advance clarification, and strategi and tactics. The collected data will be processed using N-gain to see the improvement of students' critical thinking skills before and after STEM-PBL learning is applied. With the N-gain category, (g) > 0.7 is high, 0.3 < (g) < 0.7 is medium, and (g) < 0.3 is low.

The normality test and homogeneity test were conducted with the help of IBM SPSS Statistics application. The normality test used is the Shapiro Wilk test. If the significance value $\alpha > 0.05$, then the data is normally distributed. The homogeneity test assumes that the data in each variable has a homogeneous variance with data on other variables. If the significance value $\alpha > 0.05$, then the data variance is homogeneous.

In this study, to determine whether there is an effect of the application of STEM-PBL learning on students' critical thinking skills, the paired sample t test was used. The paired sample t test method is used to compare the average of two samples taken from the same subject (paired) to analyze whether there is an influence and significant difference from the two data (Syafriani, D., et al, 2023). This analysis is used for testing comparing pretest results before treatment with posttest results after treatment. The research hypothesis is made based on the formulation of the problem, namely that there is an effect of the application of STEM-PBL learning on students' critical thinking skills (Ha). Decision making uses a significance value, namely, if $\alpha < 0.05$ then H_0 is rejected, if $\alpha > 0.05$ then H_0 is accepted.

RESULTS AND DISCUSSION.

Results

STEM-PBL learning in this research was conducted over 4 meetings. The learning process consisted of scientific practice and engineering practice stages. The first, second, and third meetings were focused on scientific practice, while the fourth meeting focused on engineering practice. Throughout the implementation of STEM-PBL learning, observations were made on student activities and teacher involvement, which were recorded in the observation sheets for STEM-PBL implementation.

Table 2. Implementation of STEM-PBL Learning

No.	STEM-PBL Stages	Learning Activities	Average Implementation
	Scientific Practice and Engineering Practice		
1.	Problem orientation - Asking question and defining problems - Developing and using models	- Students listen to the demonstration of experiments or videos presented by the teacher - Students ask questions, formulate problems, and hypotheses related to the demonstration or video	100%
2.	Organizing students for learning - Planning and carrying out investigations	- The students work in groups to complete the assignment	100%

No.	STEM-PBL Stages	Learning Activities	Average Implementation
		- The teacher distributes the assignment and explains the technical aspects of completing	
3.	Guide the investigation - Planning and carrying out investigations - Analyzing and interpreting data - Using mathematics and computational thinking - Constructing explanations and designs solutions	- Students plan and conduct investigations to gather data - Student collect information from various sources to aid in problem-solving processes - Students discuss to determine variables based on the generated data	100%
4.	Developing and presenting works - Engaging in argument from evidence	- The students present the results of their work and the LKPD that has been created	100%
5.	Analyze and evaluate problem-solving - Engaging in argument from evidence - Obtaining, evaluating, and communicating information	- Students ask, respond to, or correct the results of group presentation discussions - The teacher reinforces concepts and materials from problem-solving - The teacher and students together draw conclusions from the learning that has been done	100%
	Average Total		**100%**

Based on Table 1, the percentage of implementation of STEM-PBL learning shows an overall average of 100% with an excellent category. This indicates that all teacher and student activities during the learning process were carried out very well. Therefore, it can be said that the implementation of STEM-PBL learning is very good

In this study, students' critical thinking skills were measured using a total of 10 description questions. The indicators of critical thinking skills in basics clarification, bases for a decision, inference, advance clarification, and strategy and tactics. Each indicator is represented by two items of description questions.

The purpose of this research is to find out how to improve students' thinking skills after the implementation of STEM-PBL learning. To find out the increase in critical thinking skills after the treatment, data analysis is needed using the N-gain. Data analysis using N-gain is carried out on pretest and posttest data to see the improvement of students' critical thinking skills before and after treatment. The results analysis N-gain can be seen in Table 3.

Table 3. N-gain Test Results of Critical Thinking Skills Indicators

Indicators of Critical Thinking Skills	No	Average *Pretest*		Average *Posttest*		N-gain	Category
		Item	Total	Item	Total		
Basic Clarification	1	66.4	66	91.4	87	0.61	Medium
	2	65		82.1			
Bases for a decision	5	46.4	53	75.7	77	0.51	Medium
	6	60		78.6			
Inference	7	69.3	61	87.1	82	0.53	Medium
	8	53.6		76.4			
Advance Clarification	3	64.3	75	67.9	81	0.24	Low
	4	85.7		94.3			
Strategy and Tactics	9	33.6	40	80.7	75	0.59	Medium
	10	45.7		69.3			
N-gain Total						**0.5**	**Medium**

Based on the result above, overall, the increase in students' critical thinking skills was in the medium category with an N-gain of 0.5. The largest increase in critical

thinking skills indicators, is the indicator of basics clarification, is in the medium category with an N-gain of 0.61. While the indicator with the smallest N-gain acquisition is the indicator of basics clarification in the low category with an N-gain of 0.24.

Normality test is conducted to identify the results of pretest and posttest data on critical thinking skills have a normally distributed data population. The results of the normality test are presented in Table 4.

Table 4. Normality Test Results Using IBM SPSS Statistics

Test of Normality				
		Shapiro-Wilk		
Aspect	Hasil	*Statistic*	df	Sig.
Critical Thinking Skill	*Pretest*	.985	35	.897
	Posttest	.943	35	.071

Based on the table, it can be seen that all data has a significance value (sig.) more than the significance level α = 0.05. Therefore, it can be said that all data is normally distributed. After doing the normality test, it is also necessary to do a homogeneity test to find out whether the data is homogeneous or not. The results of the homogeneity test are presented in Table 5.

Table 5. Homogeneity Test Results Using IBM SPSS Statistics

Test of Homogeneity of Variance					
		Levene Statistic	df1	df2	Sig.
Critical Thinking Skill	Based on Mean	.109	1	68	.742
	Based on Median	.093	1	68	.761
	Based on Median and with adjusted df	.093	1	66.316	.761
	Based on trimmed mean	.107	1	68	.742

Based on Table, the homogeneity test results show that the pretest and posttest data have a sig value in the based on mean row of 0.761. This significance value is greater than the specified significance level α = 0.05, so it can be concluded that the variants of the pretest and posttest class data are homogeneous.

The effect of the application of STEM-PBL learning on students' critical thinking skills can be seen by using the critical thinking test. skills can be seen by using the paired sample t test. The results of the paired sample t test are presented in Table 6.

Table 6. Paired Sample t test Using IBM SPSS Statistics

Paired Samples Test									
	Paired Differences					t	df	Significance	
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				One-Sided p	Two-Sided p
				Lower	Upper				
Pre Test - Post Test	-21.3571	10.7502	1.81712	-25.0499	-17.6643	-11.75	34	<.001	<.001

Based on Table 5, it can be seen that the significance value is <.001 which is less than 0.05, which means that Ha is accepted and H_0 is rejected. This shows that there is

an effect of the application of STEM-PBL learning on students' critical thinking skills.

Discussion

STEM-PBL learning is an approach that integrates four aspects of knowledge and skills: science, technology, engineering, and mathematics, by combining the Problem Based Learning model. The goal of STEM-PBL learning is for students to acquire knowledge and understanding of science, technology, engineering, and mathematics simultaneously in a single learning experience, so that this understanding can be used to solve problems and make decisions.

STEM is designed to develop various 21st-century skills that can be used in all areas of daily life, such as reasoning, problem-solving, critical thinking, creative skills, investigation, independent learning, technological literacy, teamwork and collaboration, and various other skills (Zubaidah, S, 2019). Problem Based Learning (PBL) is a learning model that uses real-world problems as a context for students to learn critical thinking and problem-solving skills, as well as to acquire essential knowledge and concepts from course materials or subjects (Kurniansyah, A F, 2018). Through learning with the Problem Based Learning (PBL) model, it is expected that students can develop critical thinking skills as a step in solving the problems discussed in the material, and can draw conclusions based on their understanding (Arifah, N, et al, 2021).

STEM-PBL learning integrates the stages of PBL with the framework or perspective of the STEM approach Each learning activity conducted is an implementation of the STEM approach framework The stages of STEM-PBL learning include problem orientation, organizing students, guiding investigations, presenting work results, and analyzing and evaluating a problem-solving process.

The characteristics of STEM-PBL learning to enhance students' critical thinking skills are: 1) integrating STEM disciplines, 2) using problem-based learning (PBL), 3) contextual and relevant learning to real-life situations, 4) student-centered learning with active student involvement, and 5) developing 21st-century skills, including critical thinking.

STEM-PBL learning is able to improve students' critical thinking skills. Each indicator of critical thinking skills is trained in learning both at the scientific practice and engineering practice stages. The indicator with the highest N-gain score is the indicator of basics clarification trained at the problem orientation stage with activities to formulate problems and formulate hypotheses. During the learning process, students are always involved in the process of identifying and solving problems based on data and evidence, so that students can easily answer the indicator basics clarification with sub-indicators focusing on the problem. The form of questions on this indicator is similar to the activities of formulating problems and hypotheses. Learners are asked to make a question based on the data and images presented in the problem. The activities of formulating problems and formulating hypotheses are considered effective for improving critical thinking skills on the indicator of basics clarification with an N-gain of 0.61 with a moderate category. This shows that STEM-PBL learning can improve students' ability to identify and analyze problems (Putri, D. C., et al., 2020).

The indicator of bases for a decision is trained at the stage of guiding the investigation with data collection activities. Learners conduct experimental activities through Phet, determine variables from the

data provided, make designs/prototypes and look for supporting information through various sources. Data collection activities are considered effective for improving critical thinking skills on bases for a decision indicators with an N-gain of 0.51 with a moderate category.

The inference indicator is trained at the stage of guiding the investigation and analyzing and evaluating problem solving. At the stage of guiding the investigation, students are asked to make conclusions on the results of the discussion filled in the LKPD. While at the stage of analyzing and evaluating, students together with the teacher make conclusions from the learning that has been done. The activity of making conclusions is considered effective for improving critical thinking skills on the inference indicator with an N-gain of 0.53 with a moderate category.

Indicators of strategy and tactics are trained in every lesson and LKPD work. This is because students are required to determine the steps that will be taken to solve the problem and formulate possible alternatives as a solution to the problem. In detail, the ability of strategies and tactics is trained at the stage of analyzing and evaluating problem solving, developing and presenting results, and guiding investigations. At the stage of analyzing and evaluating problems, students are asked to engage in arguments by providing responses and comments related to the results of the LKPD work of the presentation group. At the stage of developing and presenting the results, students are asked to communicate the results of the LKPD work in groups. Then at the stage of guiding the investigation, the ability of strategy and tactics is trained in the activity of making experimental procedures. These activities are considered effective for improving critical thinking skills on strategy and tactics indicators with an N-gain of 0.59 with a moderate category.

The indicator of advance clarification is trained at the stage of conducting investigations with data processing activities. The activity directs students to answer questions on the LKPD, find variable values using math and convert data into graphs. In this activity, students tend to still have difficulty converting data into graphs and analyzing the relationship between available variables. So that this activity is considered ineffective in training critical thinking skills in the advance clarification indicator with the lowest N-gain of 0.24 in the low category. It can be seen from the low increase in students' pretest and posttest results on questions that measure advance clarification indicators. The following is a recap of students' answers in Table 7.

Table 7. Recap of Answers to Question Number 3 Indicator Advance Clarification

		Question 3
Student	**Test**	**Answer**
MFM	*Pretest*	Tabel c, karena proses menyublim dan menguap menyerap kalor dan membeku melepas kalor.
	Posttest	Tabel C, karena proses menyublim dan menguap memerlukan kalor dan proses membeku melepas kalor.
STT	*Pretest*	tabel A Menguap adalah perubahan wujud yang memerlukan kalor atau pemanasan.
	Posttest	sedangkan membeku dan menyublim melepas kalor
ND	*Pretest*	Tabel A, karena
	Posttest	Tabel C, karena menyublim dan menguap merupakan perubahan zat yang memerlukan kalor (penyerapan suhu) dari rendah ke tinggi, sedangkan membeku merupakan perubahan zar melepas kalor (penurunan suhu) dari tinggi ke rendah

Question 3		
Student	**Test**	**Answer**
HGM	*Pretest*	Tabel B, karena gas dapat merubah wujud menjadi zat cair apabila melepas kalor, begitupun proses pencairan dapat berbah wujud karena memerlukan kalor.
	Posttest	tabel C, karena ikatan molekul akan terlepas apabila terjadi proses penyerapan kalor

Table 7 show the pretest and posttest answers of students on questions number 3 which measure the indicator of advance clarification. In question number 3, learners are asked to select the correct table of changes in the form of the correct substance and provide a complete explanation related to the table. At the time of the pretest, there were still many students who gave incorrect explanatory answers even without explanation so that the average score on this question was 64.3. Whereas during the posttest, students were able to choose the correct table but the explanation given was considered less precise and incomplete so that the scores obtained tended to be small. This resulted in the average posttest score on this question being small, which was 67.9.

Overall, the application of STEM-PBL learning is able to improve students' critical thinking skills. STEM-PBL learning facilitates students in developing and practicing critical thinking skills through formulating problems and hypotheses, planning and conducting investigations, gathering information, analyzing and processing data, finding solutions, discussing and engaging in arguments, and evaluating and communicating solutions. This is in line with research conducted by Putri, D. C., et al. (2020) who stated that STEM-PBL learning can facilitate students to practice critical thinking skills at each stage of learning. The ability of students to analyze problems, design tools, interpret data, and provide explanations can be trained through the learning process with PBL-STEM. Other research suggests that learning integrated with STEM is able to facilitate students to develop 21st century skills, namely adaptation, communication and social skills, problem solving, self-management and self-development, and critical thinking or systematic thinking (Bybee, 2011). Zulfawati, Z., et al. (2022) stated that the application of STEM-integrated Problem Based Learning can improve students' critical thinking skills in the medium category. The application of PBL-STEM online can improve students' critical thinking skills with an N-gain value of 0.72 in the high category (Putri, D. C., et al., 2020). Similar research states that improving students' critical thinking skills using the STEM-integrated Problem Based Learning model is proven to significantly improve the critical thinking skills of a class group compared to a class group that uses conventional learning (Nurazmi, N., & Bancong, H., 2021).

The data obtained were normally distributed and homogeneous. The hypothesis test conducted shows that H_0 is rejected and H_a is accepted. This shows that there is an effect of the application of STEM-PBL learning on students' critical thinking skills. In line with previous research conducted by Zulfawati, Z., et al. (2022) that the results of his research stated that the STEM-integrated Problem Based Learning learning model effectively improved students' critical thinking skills. The STEM-integrated Problem Based Learning model can improve critical thinking skills because during learning students are accustomed to identifying and finding solutions to problems using the four aspects of knowledge, namely science, technology, mathematics, and engineering. In Zulfawati's Z., et al. (2022) research, also

learning is assisted by STEM-based LKS which asks students to carry out the process of observing to conclude. STEM-integrated PBL learning has been proven to significantly improve students' critical thinking skills (Ramli, Y., & Irawan, F., 2023). Therefore, this study also has similar results that the application of STEM-PBL learning can affect the improvement of students' critical thinking skills.

CONCLUSION

Based on the results of research and discussion, the stages of STEM-PBL learning include problem orientation, organizing students, guiding investigations, presenting work results, and analyzing and evaluating a problem-solving process.

The characteristics of STEM-PBL learning to enhance students' critical thinking skills are: 1) integrating STEM disciplines, 2) using problem-based learning (PBL), 3) contextual and relevant learning to real-life situations, 4) student-centered learning with active student involvement, and 5) developing 21st-century skills, including critical thinking.

STEM-PBL learning can improve students' critical thinking skills in the medium category with an N-gain of 0.5. The indicators basic clarification is in the medium category. The indicator bases for a decission is in the medium category. The indicator inference is in the medium category. The indicator advance clarification is in the low category. Strategy and tactics indicators is in the medium category.

The implementation of STEM-PBL learning has a significant impact on students' critical thinking skills. In other words, there is a significant difference in students' critical thinking skills before and after the implementation of STEM-PBL.

This research can be strengthened by having a control group to compare the results of STEM-PBL learning in the experimental class with the more objective PBL learning in the control class Furthermore, STEM-PBL learning can be implemented through direct laboratory experiences so that students can gain deeper investigative and experiential processes, ultimately enhancing their critical thinking skills.

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