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Enhancing Senior Students Critical Thinking Skills on Thermodynamics Topic Using Problem-Based Learning Integrated with STEM

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Abstract
This study aims to determine the improvement of students' critical thinking skills related to the topic of thermodynamics which is taught using a stem-integrated problem-based learning model. The research subjects were 52 students of class XI MIPA 2 and XI MIPA 3 SMAN Pronojiwo. The research model used was explanatory methods. The results of this study indicated that the initial critical thinking ability of the control class students was higher than the experiment class, with medians of 8 and 6.5. After the intervention, the obtained median values of 10 and 10 with the Mann-Withney test P 0.05, signifying no difference after the intervention. In addition, students' abilities in the category of problem-solving, hypothesizing, and reasoning abilities experienced positive changes.
Keywords: Critical thinking skills, problem-solving, problem-based learning, STEM, thermodynamics

Abstrak
Penelitian ini bertujuan untuk mengetahui peningkatan kemampuan berpikir kritis terkait topik termodinamika yang diajarkan dengan menggunakan pembelajaran berbasis *problem based learning* terintegrasi STEM. Subjek pada penelitian ini adalah siswa pada kelas XI MIPA 2 dan XI MIPA 3 SMAN Pronojiwo sebanyak 52 anak. Desain Penelitian yang digunakan adalah *Explanatory methods*. Hasil penelitian ini menunjukkan kemampuan awal berpikir kritis siswa kelas konvensional lebih tinggi dari kelas permodelan dengan median 8 dan 6,5. Perubahan setelah intervensi perolehan nilai median sebesar 10 dan 10 dengan uji mann-withney P ≥ 0,05 menyatakan tidak ada perbedaan atau sama setelah intervensi. Selain itu kemampuan siswa mengalami perubahan yang positif pada rubrik kemampuan pemecahan masalah, berhipotesis dan penalaran.
Kata Kunci: keterampilan berpikir kritis, pemecahan masalah, pembelajaran berbasis masalah, STEM, termodinamika

1. Introduction

Thermodynamics is one of the essential topics in physics. It is applied in numerous technologies used in everyday human life. However, many students face difficulties in comprehending the concepts of thermodynamics [1]. Great comprehension of thermodynamics concepts is crucial to generating human resources with excellent problem-solving and critical thinking skills [2]. Students with exceptional critical thinking skills are capable of solving problems effectively [3]. In constructing and assessing whether to accept or reject the obtained information, students require critical thinking skills [4].

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Several fundamental thermodynamics concepts that should be comprehended by students are internal energy, effort, and heat. Besides, students are expected to be capable of identifying efforts and heat using a P-V diagram. Previous research suggests that most students still face issues in identifying heat and internal energy, reflecting their conceptual framework [5]. Another research shows that students have issues in applying the I law of thermodynamics in various processes of thermodynamics [6]. These issues complicate students' processes of comprehending thermodynamics materials.

In order to solve these issues, a particular learning model is required to aid students, such as problem-based learning integrated with STEM. A previous study identifies that problem-based learning integrated with STEM carries positive influences on students' behavior, primarily on their cognitive and behavioral intention [7]. Problem-based learning has been proven to grow students' active participation in the learning process [8]. Meanwhile, STEM-based problem-based learning affects students' cognitive and affective development [9]. Therefore, this study investigates problem-based learning integrated with STEM and its effects on students' critical thinking processes.

2. Research Method

This study was carried out in a cluster with a group of students selected as the samples. Two classes were selected as the control and experiment groups. The experiment class learned using problem-based learning integrated with STEM, while the control group used conventional learning. In conventional learning, the students received materials from the teachers similar to their common daily classroom learning process, with no intervention from us. The learning process was carried out in six meetings involving 56 students.

The instruments used in this study were a critical thinking skills test, syllabus, lesson plan, student worksheet, and implementation observation sheet. In the first meeting, the students were provided with a pre-test, while from the second to fifth meetings, students attended learning with a specific learning method. In the sixth meeting, a post-test was carried out to reveal the final students' critical thinking skills after the learning process. The obtained results were analyzed quantitatively using SPSS, with regard to the results of prerequisite, normality, and Mann-U Whitney tests.

3. Results and Discussion

3.1 Results

The quantitative analysis results of students' critical thinking skills pre-test are presented in Table 1.

Table 1. Analysis Results of Students' Critical Thinking Skills Pre-test

No.	Variable	Experiment Group	Control Group
1.	Median	6.5	8
2.	*Interquartile Range*	*3.25*	3
3.	Number of students	26	26
4.	Ideal score	20	20

Table 1 shows the obtained median and interquartile range of the experiment group are 6.5 and 3.25, respectively. Meanwhile, in the control group, the obtained median and interquartile range were 8 and 3, respectively. These obtained analysis results on the pre-test score showed that the students in the experiment class had lower skills than the students in the control class.

In addition, the post-test results of students' critical thinking skills are presented in Table 2.

Table 2. Analysis Results of Students' Critical Thinking Skills Post-test

No	Variable	Experiment Group	Control Group
1	Median	10.00	10.00
2	*Interquartile Range*	*4.00*	3.00
3	Number of Students	26	26
4	Ideal Score	20	20

As presented in table 2, the obtained median and interquartile range scores of the experiment group are 10.00 and 4.00, respectively. Meanwhile, the control group attained the median and interquartile range of 10.00 and 3.00, respectively. The analysis results indicated increasing critical thinking skills of the experiment class as in the previous test, where they obtained lower critical thinking scores than the control group. Further, the results of the normality test are shown in Table 3.

Table 3. Results of Normality Test on Control and Experiment Groups

Data	Group	Shapiro-Wilk		
		Statistic	Df	Sig.
Critical Thinking Skills Pre-test	Experiment	0.842	26	0.001
	Control	0.944	26	0.168
Critical Thinking Skills Post-test	Experiment	0.883	26	0.007
	Control	0.938	26	0.122

However, the parametric test could not be carried out due to some contravened assumptions. The parametric test can only be carried out if the data are homogenous and normally distributed, but our obtained data fail to meet those criteria. Therefore, the homogeneity test was not carried out. Meanwhile, the non-parametric Mann-Whitney test results are presented in Table 4.

Table 4. Results of Mann-Whitney Test of the Control and Experiment Groups

Data	N	U	P-value
Pre-test of experiment class	26	186.000	0.005
Pre-test of control class	26		
Post-test of control class	26	315.000	0.668
Post-test of experiment class	26		

According to Table 4, there were different critical thinking skills between students in the experiment and control classes, as suggested by the obtained score of U = 186.000, $p \leq 0.05$, in the experiment class before the intervention. Meanwhile, the analysis results of students' critical thinking post-test scores in both control experiment classes showed no different critical thinking skills, reflected by the obtained U= 315.000, $P \geq 0.05$ of the control class, after the intervention. Further, the overall results of the experiment and control groups were also analyzed, based on each of the item indicators, after the analysis of the average scores. The analysis results of each indicator are illustrated in Figure 1.

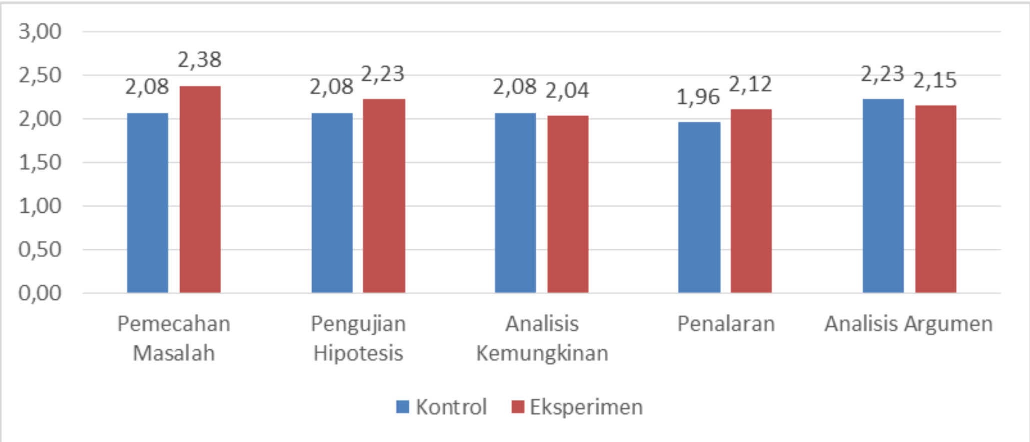

Figure 1. Analysis Results of Students' Critical Thinking Skill Post-test Score Based on Item Indicator

3.2 Discussion

In the experiment class, students presented significantly increased critical thinking skills after they attended the learning process using problem-based learning integrated with STEM. The students implemented their experience and understanding to select the proper solutions to the provided problem. In line with our findings, T. R. Kelley (2016) explains that this problem-based learning integrated with STEM can enhance students' critical thinking skills [10]. As presented in Figure 1, the students in the experiment class show better skills in completing the questions about problem-solving, hypothesis testing, and reasoning. With moderate improvement, students have been categorized as capable of analogizing a problem. Besides, students' better skills in analyzing possibilities and arguments are required.

The lower pre-test scores of the experiment class than the control groups highlight the increasing skills of students in the experiment class, as illustrated by the post-test scores. Meanwhile, the results of Mann-Whitney statistic analysis on the pre-test data showed that the control group had higher critical thinking skills than the experiment group. In contrast, the results of the Mann-Whitney test on the post-test data showed no different critical thinking skills between the experiment and control classes. In line with our finding, a previous study reported that problem-based learning integrated with STEM increases students' conceptual understanding [11]. Students with better critical thinking skills present better conceptual understanding, while most students still face challenges in applying their different knowledge [11]. Besides, this problem-based learning integrated with STEM enables students to actively and independently participate in the learning process [13]. This problem-based learning integrated with STEM trains students to independently look for knowledge. Several previous studies confirm that problem-based learning integrated with STEM better improves students' comprehension of physics materials [12] than conventional learning. An integration of problem-based learning and STEM is more effective in increasing students' mathematical scores than problem-based learning non STEM [14]. Additionally, problem-based learning integrated with STEM carries positive effects on students' behavior, primarily on students' cognition and behavioral intention [15]. STEM learning accentuates the engineering process through the establishment of a simple water heater prototype to increase students' critical thinking skills. Similarly, a study carried out by Darma, I. K (2016) concludes that engineering design-based learning aids teachers in science learning better than conventional learning [16]. Even though problem-based learning has the ability to enhance students' critical thinking, teachers still need to possess engineering competencies [18]. The learning of material design and engineering facilitates students to review the materials since the learning is closely correlated to our daily life. Besides, engineering design also helps students resolve a problem and use their critical thinking skills [19]. Students need critical thinking skills to decide whether their obtained information can be accepted or not [20].

4. Conclusion and Suggestion

After the implementation of problem-based learning integrated with STEM, students' critical thinking skills improve substantially. It signifies that problem-based learning integrated with STEM can enhance students' critical thinking skills compared to conventional learning. Additionally, future researchers are suggested to choose this learning model since it effectively improves students' critical thinking. However, they should also consider the allocated learning period and students' characteristics.

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