Journal of Physics: Conference Series

Impact of The STEM approach with formative assessment in PjBL on students' critical thinking skills

To cite this article: Parno *et al* 2022 *J. Phys.: Conf. Ser.* **2165** 012044

Impact of The STEM approach with formative assessment in PjBL on students' critical thinking skills

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Abstract. Critical thinking skills (CTS) are skills that need to be developed in the 21st century. However, building students' CTS through a STEM approach with formative assessment in project-based learning (PjBL-STEM-AF) is rarely done. This study aims to investigate the impact of STEM-AF in PjBL in constructing students' CTS in the topic of fluid statics. This study used a quasy experiment with a pretest-posttest control group design with students of class XI in Malang, Indonesia, as subjects. PjBL-STEM-AF model and the PjBL model was applied to the Experimental and Comparison classes, respectively. Students made two projects, namely a pressure element HARTL and a simple boat project. The research instrument was 9 essay items of critical thinking skills test with a reliability of 0.625. The data were analyzed by t-test, N-gain, and d-effect size. The results showed that the CTS in the Experimental class with a mean of 65.19 and an increase of 0.52 (medium) was significantly higher than the comparison class with 52.36 and 0.35 (medium). Experimental class' students have different levels of improvement on the likelihood and uncertainty analysis indicator. However, the two classes had almost the same increase in the indicator of problem-solving and decision-making, and an increase in the low category on the hypothesis testing indicator. The value of effect size at 1.13 (Very Large category) suggests that PjBL-STEM-AF learning should be done more frequently in the field. The Experimental class students gave a more positive learning response than the Comparison class. It is recommended in future studies to add an "Art" aspect to the STEM approach to develop students' CTS further.

1. Introduction

The 21st century requires communication skills, creativity, critical thinking, and the ability to manage digital information [1]. Science education should develop 21st-century skills such as critical thinking, problem-solving, and information literacy [2]. The 2013 Indonesian curriculum also aims to hone 21st-century thinking skills such as critical, creative thinking skills, and solving problems [3]. These skills are the process of thinking and behavior of students when studying content in learning. It appears that students need critical thinking skills in learning science.

Physics subjects require critical thinking skills (CTS). Critical thinking requires high-level thinking to analyze the right reasons for making decisions during solving a problem [2]. This skill refers to three cognitive complexities, namely analyzing, evaluating, and creating [4,5]. The application of CTS requires students to ask and answer their questions [6]. Therefore, CTS is not only about the process of gathering information and knowledge, but is considered as the ability to think clearly and rationally [7].

Several studies show that students still have all or some of the CTS indicators that are below expectation. The indicators of student analysis, evaluation, explanation, and conclusion drawing are still low [8]. Evaluation indicators [9], and analytical skills in physics [10] are also still low. This is due to the difficulty of students in connecting learning outcomes with actual phenomena [9]. In static fluid material, students only achieve 20% critical thinking skills [11], or less than 30% [12], or less than 50% [13]. Meanwhile, static fluid material presents daily events, solving mathematical equations, and applying technology [14]. Several studies including 5E-peer instruction learning [15], and discovery learning [16] have been carried out to build critical thinking, but the learning has not covered all the characteristics of static fluid material, and has not provided opportunities for teacher-student feedback during the learning process. Students can find problems by studying the concept of static fluid by observing the surrounding environment and solving them based on relevant theories and concepts [17]. CTS can be trained by implementing an integrated active learning project [12] and providing problem situations [18]. Learning feedback through formative assessment can help teachers and students to find the best way to learn [19,20] so that the learning process becomes perfect [21]. It appears that in static fluid material CTS can be stimulated to develop through solving everyday contextual problem situations in the form of making projects as technology miniatures in project-based learning integrated STEM approach with formative assessment (PjBL-STEM-AF).

STEM (science, technology, engineering, and mathematics) is an alternative learning approach that requires students to make miniature technology products and use them as learning media. The preparation of implementing a particular learning model that is integrated with STEM is very important to achieve learning objectives [22]. For example, the application of the STEM integrated project-based learning model (PjBL-STEM) can provide experiences related to the integration of knowledge and its application [23]. PjBL-STEM challenges, motivates, and demands students to be analytical in the process of improving higher order thinking skills [24]. It is clear that through PjBL-STEM students have experience making products as their own learning media.

In the STEM process, an assessment of PjBL-STEM learning is usually given including a summative assessment to ensure students meet the objectives [24]. This assessment is carried out at the end of the lesson to evaluate the learning that has been carried out and the time for the assessment has been set [25]. However, the assessment given only at the end of the lesson did not reveal students' thinking skills [26]. In other words, summative assessment can only measure the achievement of learning objectives, but without improving students' critical thinking skills. Therefore, a formative assessment is needed during the learning process so that it can be a means to help students apply knowledge.

Formative assessment is an appropriate assessment to help students apply knowledge during the learning process [25]. Through formative assessment, teachers can provide appropriate responses to students' learning progress. The form of the teacher's response gives is adjusted to the level of students' learning progress. Responses from teachers that will help improve students' CTS. Provision of formative assessment can be done through reports and student journals [26]. However, the PjBL-STEM model with formative assessment to build critical thinking skills on static fluid materials is still rarely done. Therefore, this study aims to investigate the effect of the STEM approach with formative assessment in the PjBL model to build students' critical thinking skills.

2. Methods

This type of research is a quasi-experimental with pretest-posttest non-equivalent group design [27]. The experimental class (n=30) applied 7 PjBL-STEM model syntax [25] with 5 domains in formative assessment [28], while the comparison class (n=22) applied 5 PjBL model syntax [29]. The subjects of this study were students of class XI SMAN 1 Malang, Indonesia, which was determined by cluster random sampling technique. The act of learning static fluid material is carried out in 2 rounds. The first round presents the sub-materials of pressure, hydrostatic pressure, meniscus, capillarity, and viscosity with products in the form of pressure element HARTL, while the second round presents the sub-materials of Pascal's and Archimides' laws with products in the form of simple boat.

The treatments given to the two classes differ, but some treatments are the same. The same treatments include (1) making the same engineering product, namely a pressure element HARTL project in the first round, and a simple boat project in the second round, (2) contextual problems in the first and second rounds of learning, each of which is a diver who died due to decompression, and road access to school was blocked by a stretch of river, and (3) syntax activities 1, 2, 3&4, 5, 6, and 7 in PjBL-STEM-AF correspond to syntax activities 1, 2, 3, 4 , 5, and 6 in PjBL, and (4) using the same length of time. The different activities between the two classes include the last syntax (1) the experimental class carries out self-assessment and peer-assessment, while the comparison class conveys difficulties in doing projects, (2) the experimental class carries out more quantitative activities in the laboratory than the comparison class, (3) the experimental class does project up to the step of improving the project that has been tested and collects reports on the results of project trials, while the comparison class only goes to project trials and collects project creation video files, and (4) the experimental class performs calculations and analyzes the result data more observations than the comparison class. The forms of formative assessment activities that are only given to the experimental class include (1) submission of project assessment criteria, (2) discussions to find the advantages and disadvantages of problem solutions, (3) the division of the second round of groups is made based on the scores of the first round of quizzes, (4) discussing design a group project with other groups, (5) write Lesson Tweets containing material that has been understood during the lesson, (6) discuss the completion of quiz questions, and (7) draw conclusions on the overall learning from the sub-materials of the first meeting to the last.

This study uses The Fluid Statics' Critical Thinking Skills Test instrument. This instrument is in the form of 9 essay questions containing indicators of critical thinking skills: reasoning, hypothesis testing, argument analysis, likelihood and uncertainty analysis, and problem-solving and decision-making [30] with reliability of 0.625. Pretest and posttest data were analyzed by independent t-test to determine the presence or absence of significant differences [31], N-gain to determine the level of improvement [32], and effect size to determine the strength of practical implementation in schools [31].

3. Result and Discussion

The data on students' CTS experimental and comparison classes are presented in Table 1 below.

Table 1. Data summary of students' critical thinking skills before and after learning

Classes	N	Before learning		After learning	
		Average	SD	Everage	SD
Experiment	30	28.27	8.22	65.19	11.20
Comparison	22	26.77	7.83	52.36	11.67

It appears that students of both classes have almost the same CTS before learning. However, after learning the experimental class students have a higher CTS than the comparison class. This means that the STEM approach with formative assessment has a positive impact on increasing students' CTS.

The results of the analysis of normality, homogeneity, and difference tests on the pretest and posttest data are presented in Table 2 below.

Table 2. The normality and homogeneity data, and different est result

<table>
<tr><th></th><th>Classes</th><th>Kolmogorov-Smirnov test (Sig.)</th><th>Levene Test (Sig.)</th><th>t Test (Sig.)</th></tr>
<tr><td rowspan="2">Pre-test</td><td>Experiment</td><td>0.200 (normal)</td><td rowspan="2">0.844 (homogen)</td><td rowspan="2">0.509
(no differences)</td></tr>
<tr><td>Comparison</td><td>0.200 (normal)</td></tr>
<tr><td rowspan="2">Post-test</td><td>Experiment</td><td>0.200 (normal)</td><td rowspan="2">0.968 (homogen)</td><td rowspan="2">0.000
(differences)</td></tr>
<tr><td>Comparison</td><td>0.200 (normal)</td></tr>
</table>

It appears that the test requirements for normality and homogeneity of the data are met so that the different test can use the independent t-test. The test results of differences in pretest data showed that the students of the two classes had no different initial critical thinking skills. This means that if there is a difference in critical thinking skills at the end of the lesson, then the difference is solely caused by the existence of different learning actions between the experimental and comparison classes. The results of the posttest data difference test showed that the experimental class students had significantly better critical thinking skills than the comparison class. This means that the STEM approach with formative assessment in PjBL has a significant positive impact in building students' critical thinking skills on static fluid material. The results of this study are in accordance with previous research that there was an increase in students' critical thinking skills after applying the PjBL-STEM model [33].

The critical thinking skills of experimental class students can outperform the comparison class because of the role of the STEM approach with formative assessment. Besides playing a role in developing thinking skills, PjBL-STEM also builds cooperative learning skills [34]. During the project creation process, the teacher monitors project progress and student learning progress in groups by ensuring each group works collaboratively to complete the project [35]. Through discussions during project trials, students are trained to develop reasoning indicators, test hypotheses in the form of interpreting relationships between variables, and analyze possibilities and uncertainties to asses the achievement of STEM aspects. Moreover, the experimental class students followed up the trial by taking steps to improve the projects that had been tested and submitting reports on the results of project trials. In addition, as many as 6 formative assessment activities, which have been mentioned in the method, were only carried out by experimental class students. One of these activities is discussing the design of the group's project with other groups. As a regulator of the discussion process, the teacher's role is to help connect the one student’s response to another [36].

The results of increasing critical thinking skills of experimental and comparison class students are presented in Table 3 below.

Table 3. The results of the N-gain calculation of experimental and comparison class students

Classes	N-gain (category)	N–gain of learning (category)	
		Cyclus 1	Cyclus 2
Experiment	0.52 (medium)	0.47 (medium)	0.80 (high)
Comparison	0.35 (medium)	0.36 (medium)	0.32 (medium)

It appears that the experimental and comparison class students have increased critical thinking skills at the same level. But in line with the results of the independent t-test, PjBL-STEM-AF learning has a higher increase than PjBL. PjBL-STEM-AF learning can produce N-gains above the active learning class average of 0.48 [37], while PjBL learning can only produce N-gains that tend to be close to the low category threshold. The improvement of students' critical thinking cannot be separated from the provision of formative assessments based on the development of knowledge and skills, discussion results, and the results of student observations during the learning process [35]. Assessment activities in the form of providing feedback in this study are based on the analysis of quiz scores and student self-assessment. Students' difficulties are discussed together in class and become a form of feedback based on knowledge and observations. In addition, students make projects up to steps to improve projects that have been tested and submit reports on the results of project trials.

Table 3 also shows that the increase in N-gain in the experimental class is higher than the comparison class, both in learning rounds 1 and 2. In this case, the provision of formative assessment in PjBL-STEM gives better results than only in the form of a summative assessment [38]. Providing formative assessment in the form of feedback can increase the quality of PjBL-STEM implementation in the classroom [39]. In fact, in the second round of learning material, STEM learning approach with formative assessment was able to increase one level above PjBl learning. Some forms of formative assessment that are only carried out in the experimental class include students writing down any material that has been well understood, and conveying the overall learning conclusion, starting from the sub-materials of the first meeting to the last.

The improvement of each student's critical thinking indicator in the experimental and comparison classes is presented in Table 4 below.

Table 4. The results of calculating the N-gain for each critical thinking indicator

Classes	Critical thinking skills indicators				
	Reasoning	Hypothesis testing	Argument analysis	Likelihood and uncertainty analysis	Problem-solving and decision-making
Experiment	0.67 (medium)	0.19 (low)	0.62 (medium)	0.44 (medium)	0.47 (medium)
Comparison	0.45 (medium)	0.14 (low)	0.48 (medium)	-0.09 (low)	0.46 (medium)

It appears that the experimental class students have an increase in N-gain greater than the comparison class on all critical thinking indicators, especially on reasoning and argument analysis indicators. In fact, different levels of improvement occurred in the likelihood and uncertainty analysis indicators. However, both classes have almost the same improvement in the problem-solving and decision-making indicators, and the low category increase in the hypothesis testing indicator.

The difference in improvement in the reasoning indicators between the two classes occurred in the completion of item number 2. This item has the aim of "Presenting the Archimedes Law lab activity, students can explain the Archimedes Law concept based on the results of the lab activity". In laboratory cases, eggs can experience 3 phenomena, namely sinking, neutral buoyancy, and floating in water that is added with different levels of salt solution. Before learning, students are only able to interpret one phenomenon. However, after learning the comparison class students were only able to interpret two phenomena, while the experimental class students were able to interpret the three phenomena. This happened because in making the project the experimental class students took steps to improve the project that had been tested, while the comparison class students only went to the project trial step. In addition, the experimental class students discussed the design of their group projects with other groups. The activities of designing projects, evaluating, and communicating project designs involve lots of ideas, creativity, and critical thinking skills [25] so as to be able to train students' reasoning indicators.

The difference in improvement between the two classes also occurs in the argument analysis indicator. In this case, the experimental class students could complete questions number 4 and 5 better than the comparison class students. Item number 4 has the objective of "Presenting an argument regarding the condition of objects in the water, students can correct errors in the argument". Experimental class students were able to analyze that the argument "Grant states that wood floats because it is 'lighter than water' and stones sink because it is 'heavier than water'' is an inaccurate conclusion statement because actually this is not related to mass, but involves density of the object. Meanwhile, the comparison class students only stated that Grant's argument was inaccurate or that the mass did not affect floating or sinking. Item number 5 has the objective of "Two pictures of dams with different shapes and an argument are presented, students can analyze the truth of the arguments put forward". In this case, the experimental class students were able to assess the credibility of the source of information that the argument "According to Risa a dam in the form of an upright beam is more effective than a beam with a larger base in retaining water because the pressure at all points on the water is the same" is not true because this is actually related to The principle of hydrostatic pressure is proportional to the depth of the water. While the comparison class students were only able to judge that the statement was not true because of the influence of hydrostatic pressure.

Students of both classes had almost the same improvement in items number 1 and 8 for the problem-solving and decision-making indicators. In item number 1 which aims "A paper clip experiment is presented, students can find the source of the problem and plan possible solutions based on the instructions given". Students of both classes were able to do the problem-solving and decision-making about “Ani conducted an experiment by putting a paper clip into a vessel filled with water using a toothpick. It turns out that paper clips can float on the surface of water. What should Ani do to make the paper clip sink to the bottom of the water without touching it?” by heating water in a vessel or dissolving a surfactant so that the surface tension of the water is reduced so that the paper clip sinks. It appears that the students of both classes are able to identify the parts of the problem and adjust the solution plan. Item number 8 has the aim of "Presenting a fragment of the hydrostatic pressure experiment step, students can determine the appropriate practicum objectives". In this case, based on several practicum steps provided, students can recognize the parts of the problem and adjust the solution plan by accurately formulating the practicum objectives, namely to determine the effect of fluid depth on hydrostatic pressure. Students can also develop their hypothesis, namely that the greater the difference in the height of the liquid surface in the two U pipes, the greater the hydrostatic pressure measured.

In item numbers 1 and 8 above, students have the least difficulty among the other questions. Based on the results of the interviews, this happened because more than 50% of students had studied this material before. In addition, both classes have the same steps in project creation, namely up to the project pilot step. Critical thinking skills in problem-solving and decision-making are developed through identifying emerging ideas and developing one reasonable and creative solution [40]. Asking important questions related to the idea or concept being studied is a way of learning through the design being developed [41]. It is clear that the critical thinking skills that are trained in the activities of designing, evaluating, and communicating projects are problem-solving and decision-making.

In item number 7, experimental class students have a much greater increase in critical thinking than comparison class students, which occurs in the indicators of likelihood and uncertainty analysis. This item has the objective of “Presenting an oil drop experiment, students can calculate the magnitude of the velocity of oil in the air”. In this case, students are required to calculate the possible values expected from the experiment, namely analyzing known quantities, writing equations to find the terminal velocity, and finding the exact value of the terminal velocity. Before learning most of the students did not know anything about this problem. The results of the interviews showed that around 74.9% of students had never studied this material at all. After learning the comparison class students were only able to recognize known quantities, while the experimental class students were able to continue even though only to determine the terminal velocity formula. The results of the interview showed that about 24.1% of students had studied the sub-material, but could not solve the problem because they did not understand or did not remember. It appears that this item is quite difficult for students. In fact, both classes conducted problem-based learning. This learning is seen as an appropriate activity in developing critical thinking skills [42]. The process of problem identification and investigation has given students an idea of the purpose of making the project [25]. Activities undertaken to train critical thinking skills are asking fundamental questions based on problem identification, analyzing information, and proposing solutions. Asking questions to understand an event is a form of reasoning ability, choosing the information needed and making conjectures is a form of ability to analyze possibilities and uncertainties [40]. However, the STEM approach with formative assessment causes experimental class students to be better able to develop indicators to analyze possibilities and uncertainties.

Students of both classes increase critical thinking in the low category, which occurs in the hypothesis testing indicator represented by item number 3. This item has the goal of "Presenting 3 pictures of water in a vessel with different upper cross-sectional area, but the same lower cross-sectional area, students can prove that the magnitude of the downward hydrostatic force by the water at the bottom of the three vessels is the same”. In this case the students of both classes have not been able to test the hypothesis so that they cannot draw valid conclusions from the available information. Students should be able to conclude that the downward hydrostatic force is the same and prove it through the equation $F=pA=\rho ghA$. It appears that students still think that hydrostatic pressure is influenced by the value of cross-sectional area [43] or the fluids' volume [44,45].

Calculation of effect size produces d-effect size = 1.13 (Very Large category). This shows that the implementation of PjBL-STEM-AF actions in the experimental class, and PjBL in the comparison class is highly recommended to be carried out in schools. The actions of these two actions have a very large impact on students in building critical thinking skills.

The results of the questionnaire on students' responses to the learning process are presented in Table 5 below.

Table 5. Positive students' response for learning process in experiment and comparison classes

Classes	Students' response		Total (%)
	Agree (%)	Very Agree (%)	
Experiment	43.64	51.82	95.46
Comparison	65.68	26.36	92.05

It appears that the experimental class students gave a slightly higher positive response than the comparison class. The comparison class is not a control class because it is taught using the PjBL model. It means that in general students feel comfortable in both classes. However, in the Very Agree option, the experimental class students gave a much higher response than the comparison class. This means that the PjBL-STEM approach learning with formative assessment in the experimental class is able to provide a higher sense of comfort than PjBL in the comparison class. This result follows the response to research that states that students positively respond to the application of STEM in PjBL [46]. Also, learning physics with the STEM approach ensures that students are more comfortable than without the STEM approach [47].

4. Conclusion

Before learning the experimental and comparison class students, each had an average critical thinking ability score of 28.27 and 26.77 so that both had the same initial state. After learning PjBL-STEM-AF students had an average critical thinking ability score of 65.19 which was significantly higher than PjBL students in the score of 52.36. The improvement of critical thinking ability of experimental class students N-gain = 0.52 (medium) is also better than the comparison class N-gain = 0.35 (medium). In the review of critical thinking ability indicators, the experimental class' students have different levels of improvement on the likelihood and uncertainty analysis indicator. However, the two classes had almost the same increase in the indicator of problem-solving and decision-making, and an increase in the low category on the hypothesis testing indicator. The value of effect size at 1.13 (Very Large) suggests that PjBL-STEM-AF learning should be done more frequently in the field. The Experimental class students gave a more positive learning response (Very Agree) than the Comparison class. It is recommended in future studies to add an "Art" aspect to the STEM approach to further develop students' CTS.

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