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## The effectiveness of STEM approach on students' critical thinking ability in the topic of fluid statics

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**Abstract.** Critical thinking is a skill which ranks first in STEM activity in the 21st century learning, whereas research about the effectiveness of STEM approach implementation to increase students' critical thinking ability (CTA) is still limited. The aim of this study is to investigate the effectiveness between 7E LC and STEM-Based 7E LC models on increasing students' CTA in the material of Fluid Statics with a quasi-experiment research and Pre- and Post-test Design. The subject of the research was senior high school students in Malang, Indonesia, which was distributed in Experiment (STEM-LC) and Comparison (LC) classes. The Experiment class planned, made, and tested 2 engineering products, namely a miniature of hydraulic lift and submarine. Critical Thinking Skills Test instrument was used with the alpha Cronbach reliability of 0.94. The data was analyzed using Wilcoxon Signed Ranks test, N-gain, Mann-Whitney U test, ANCOVA, and effect size. This research found that both models were effective in building students' CTA. Furthermore, the enhancement in students' skill was affected by the different initial state and the different treatment of learning. However, both are independent of each other. STEM-LC model resulted in significantly better CTA in students than LC model. However, STEM-LC model was more effective than LC. The field practice of the STEM-LC method had a medium impact than the LC method in increasing students' ability.

### 1. Introduction

Daily phenomena and the application of technology cannot be separated from fluid statics [1]. With Newton's Laws as an important component, fluid statics covers the sub materials of density, hydrostatic pressure, and two principles, namely Pascal and Archimedes [1,2]. However, students still have difficulties in understanding the material of fluid statics [3]. For example, students still experience difficulties to note a difference between the phenomena of floating and sinking [4], have misconceptions on buoyancy and hydrostatic force [5], and presume that hydrostatic pressure is correlated with cross-sectional area [6] or the volume of the fluid [7,8,9]. These difficulties in understanding the concepts is strongly correlated with student's critical thinking ability (CTA) [10]. Critical thinking is one of the higher-order thinking [11]. To make correct decision, critical thinking involves rational and reflective thinking [12], identification of assumption, mistakes, and information [13], and facts evaluation and deduction [14]. However, students' critical thinking ability is still poor on making a conclusion, strategy, and technique in the material of fluid statics [15], in the sub material of hydrostatic pressure, and two principles, namely Pascal and Archimedes [16], and in general on the theory of physics [17,18,19]. It's apparent that the characteristics of the topic of fluid statics demand the presence of good understanding about mathematical equations used in Newton's laws as tools to solve daily contextual problems and the involvement of technology and critical thinking.



Critical thinking ability can be developed in physics learning [20] with intensive learning and sustainable practice [21]. However, students tend to only memorize the lesson so their conceptual understanding is lacking in physics learning because it's only focused on the gain of declarative knowledge to solve problems [22]. Meanwhile, few learning methods had been applied to construct critical thinking ability of students on the topic of fluid statics, for example, the 5E-peer instruction learning which is still not able to construct the inference of critical thinking [23], while PjJBL-self regulated learning [22] and discovery learning [24] are effective to increase critical thinking ability. However, these studies hadn't fully cover the characteristics of the topic of fluid statics above. The involvement of the aspect of mathematics and technology is not optimal yet. Contextual daily problems are not solved with the involvement of several procedures in engineering product design and the scope hasn't been extended critically, which will need to involve the aspects of technology, science, and mathematics. The involvement of the aspects of science, technology, engineering, and mathematics is in accordance to the STEM approach and the extended contextual problems are in accordance to 7E Learning Cycle (LC). It's apparent that to improve the construction of students' CTA in the topic of fluid statics, STEM education, which is combined with 7E LC, is needed.

STEM education is one of learning approaches which is suitable to enrich the 21st century skills [25,26,27]. STEM puts critical thinking as the activity which should be done first in 21st century learning [25]. STEM focuses on the process of critical thinking in solving contextual problems by transforming ill-defined tasks to be well-defined outcomes in teamwork environment [28]. STEM simultaneously integrates 4 aspects, which are science, technology, engineering, and mathematics [29,30] with more meaningful learning contexts [31] so that the quality of learning process can improve [32,33] and that students' knowledge and skills can be constructed thoroughly [34,35,36]. In STEM approach, students can think critically so they can solve problem in a better way, be a more logical thinker, be a more creative innovator, be more independent, and be more literate in the world of technology [37]. It's clear that the implementation of STEM education involves contextual solution, critical thinking, and mathematical and technological aspect is suitable with the demands of the characteristics of the topic of fluid statics.

The STEM learning cycle fulfils the Piaget's learning theory and it has specific features, for example, it helps students to think from concrete things to abstract things, it needs students' active role to solve contextual problems critically, and it helps students to construct new concept based on their initial knowledge [38]. It's apparent that the STEM learning approach is suitable with the characteristics of fluid statics. Problem solving which is done in groups is one of the characteristics of physics learning [39] which can help students to be more flexible in forming their thinking pattern [40]. A finding of a study stated that 7E model is able to improve students' CTA [41,42]. It's clear that 7E LC model is able to build students' CTA. Meanwhile, the combination between STEM education and 7E LC model is still rarely implemented. Learning method with STEM integration helps students in making designs, make use of technology, enhance the three components of learning output, and apply the knowledge in technology [43]. 7E Learning Cycle method is implemented with the use of STEM aspects. The integration of four aspects of STEM in 7E Learning Cycle helps students to solve contextual problems critically. It's apparent that STEM education-based 7E LC can solve contextual problem more thoroughly than 7E LC model. The aspect of STEM which plays a big role in problem solving is the aspect of engineering, which consists of 7 steps [44]. It's apparent that STEM education in 7E LC is based on the constructivist theory although in practice it is rarely implemented in real world.

Based on the introduction above, STEM approach in 7E Learning Cycle is an appropriate learning method to be implemented in suitable steps to develop students' critical thinking ability. Therefore, the purpose of this research is to test the effectiveness of STEM approach by comparing between the affectivity of STEM-based 7E LC and 7E LC models in increasing students' CTA in the material of Fluid Statics.

## 2. Method

This quasi experimental with Pre- and Post-test Design [45] research used 68 grade XI students of Public Senior High School in Malang, Indonesia, as the research participants. They were equally assigned into the Experiment (STEM-based 7E LC) and the Comparison (7E LC) classes. The description of the

integrated learning between phases of 7E LC [46] and the aspects of STEM [30] in building the indicators of critical thinking ability is as follows [47]. The phases of Elicit and Engage involve students' initial knowledge by utilizing media and case examples. The Elicit phase only involves one aspect of STEM, which is science, and train the indicator of interpretation; while the Engage phase involves science and engineering and it trains the indicator of analysis. On the phases of Explore, Explain, Elaborate, and Evaluate, students explore the knowledge and concept with the activity of observation, data gathering, and hypotheses formulation until new knowledge is gained and used to solve a problem. Four STEM aspects are involved in Explore phase. The engineering, science, and mathematics aspects are involved in the Explain, Elaborate, and Evaluate phases. The Explain phase trains the indicator of evaluation and inference, while Evaluate phase trains the indicator of explanation and self-regulation. On the Extend phase, students develop the result from the Evaluate phase and present it to train the students to make connection of the contextual knowledge in order to widen their understanding. The technology, science, and mathematics aspects are involved in the Extend phase. The aspect of engineering dominates the integration of STEM approach into 7E LC. This aspect has 7 steps, which are identification of contextual problem, exploration of many alternatives of possible solution, selection of the best solution, making the design and the miniature product, testing of product, modification of product, and evaluation of the whole process [44]. In this research, students in Experiment class endeavor in making two products, which are miniature of hydraulic lift and submarine, and complete them with poster and written report of the products.

In this research, we develop the Critical Thinking Skills Test instrument in the form of essays which cover the indicators of Interpretation, Analysis, and Inference [47]. The scoring of students' response is done with rubric from "no answer" until "complete and correct answer" with the score of 1, 2, 3, or 4. The content and construct validation was done with 2 experts. The empirical validation involved 200 twelfth-grade students who had learned the topic of fluid statics before. This validation resulted in the alpha Cronbach reliability score of 0.94. The pre-test data differences of each class is analyzed using the Wilcoxon Signed Ranks test [48], and N-gain [49]. A learning model can be considered as effective in improving students' CTA if the post-test and pre-test data are significantly different and yields the N-gain score at least on the category of medium. The pre-test and post-test data differences of both classes are analyzed with Mann-Whitney U test and ANCOVA [50] to measure the impact of learning model towards the increase of students' CTA. Then, the post-test data of the experiment and comparison classes is analyzed with d-effect size to measure the impact of the models' practicality on building the dependent variable [48].

### 3. Result and Discussion

The average score and standard deviation (in brackets) of pre-test and post-test for Experiment class are 43.14 (5.61) and 89.03 (12.45), respectively; while for Comparison class are 29.17 (14.54) and 83.50 (7.42), respectively. It can be seen that the post-test score of both classes is higher than pre-test score. Also, the pre-test of Comparison class is higher than Experiment class, but on the contrary, the post-test of Comparison class is lower than Experiment class.

The result of Kolmogorov-Smirnov normality test for the pre-test and post-test data above yields the result, respectively, Sig. 0.031, 0.000, 0.000, and 0.000. This means that all data is not normally distributed. Therefore, Wilcoxon Signed Ranks test is utilized to test the presence of difference between the pre-test and post-test pairs of every class. The result of this test yields the same result in both Experiment and Comparison class, which is Asymp. Sig. (2-tailed) 0.000. This means that the post-test of Experiment and Comparison classes is significantly higher than pre-test score. The result of N-gain test for Experiment class is 0.810 (high category), and for Comparison class is 0.772 (high category). As both classes show significantly higher post-test score than pre-test score, and as the N-gain of both classes are above the medium category, it can be concluded that both models, which are STEM-7E LC in Experiment class and 7E LC in Comparison class, were effective in building students' CTA.

The result of this research show that STEM-7E LC in Experiment class is effective in building students' CTA. The concepts in a topic of Physics are often taught separately. However, in STEM education, students solve daily contextual problems based on their relevant experience. This causes the rise in students' motivation which leads to more concepts to be learned and understood [51]. Besides,

the motivation can trigger the growth of students' aspiration, inspiration in future career, and interest in mathematics and science [52]. STEM approach can increase students' critical thinking ability which then affects greatly towards the process of decision making and students' mental in solving problem [53]. STEM education has potential to improve upon individual's skills in 21st century, such as collaboration, curiosity, creativity, and critical thinking [54]. STEM education can prepare the students to face global challenge with exercises in collaboration, problem solving, critical thinking, creativity, and innovation [55]. It's clear that STEM approach can enhance students' CTA effectively.

Another finding of this research is that 7E LC model in Comparison class was effective in building students' CTA. Students are actively being involved in 7E LC learning, especially in 4 steps, which are elicit, engage, explore, and evaluate, so that students can build the indicators of critical thinking skills. Students which are active in learning will be able to promote their scientific reasoning skill by constructing their critical thinking skills [56]. This finding supports the results of few previous studies. For example, students' critical thinking skills can be built more effectively in 7E LC model than in conventional learning model [41], can be increased better in 7E LC than in conventional model [57], and can be generated better in 7E LC than in expository model [58]. It's clear that 7E LC model can effectively build students' CTA in learning.

In order to examine the effect of treatment towards building students' CTA, homogeneity of variance is required. The result of Lavene statistic test of homogeneity variance yields the result of Sig. 0.000 and 0.003, respectively for pre-test and post-test. This means that both data do not fulfil the homogeneity variance requirement. As both pre-test and post-test data do not fulfil the normality distribution and homogeneity of variance, the difference test between pre-test and between post-test of both classes is done with Mann-Whitney U test. The result of Mann-Whitney U test on pre-test data yields the result of Asymp. Sig. (2-tailed) 0.000, which means that there is difference between pre-test of both classes. This implicates that both classes started with different condition of students' CTA. To remove the effect of this initial condition of CTA towards the final score of students' CTA at the end of the learning, ANCOVA analysis is conducted by making the initial condition (pre-test score) as covariate variable.

The prerequisite test of ANCOVA, which is Tests of Between-Subjects Effects, produces Sig. 0.656. This means that there is no interaction between post-test data as independent variable and pre-test data as covariate variable so that ANCOVA test can be conducted. ANCOVA test yields the result of Sig. 0.18 for covariate variable, and Sig. 0.25 for model variable. This result indicates that the enhancement in students' critical thinking skill was affected by the different initial state and the different treatment of learning. However, both are independent of each other. The "adjusted" data shows that the average score and SD for posttest data of Experiment and Comparison class, respectively, are 88.16 (1.93) and 84.37 (1.93). It can be seen that after the initial skill was made as covariate variable, the average score of post-test of Experiment class goes down, and the average score of post-test of Comparison class goes up. Therefore, the post-test data of both classes tend to go towards the same (similar) score. This happens because the covariate variable also has an impact towards the enhancement in students' critical thinking skill. However, the change of value is not too significant which leads to the conclusion that the different treatment of learning still has an impact towards the enhancement at the end of the learning [50].

Based of ANCOVA test, students' skill was affected by the different treatment of learning. As the post-test of both classes was not normal and was not homogeneous, the difference test between both was done with Mann-Whitney U test. The result of the test yields the value of Asymp. Sig. (2-tailed) 0.010, which means that there is significant difference between post-test of both classes. As the average score of post-test of Experiment class is higher than Comparison class, it can be said that STEM-LC model can build students' CTA significantly better than LC model. As the result of this, and considering that both classes were effective in building students' CTA as mentioned before, it can be said that the STEM-LC model was more effective than LC in building students' CTA.

Experiment class conducted two cycles of STEM-7E Learning Cycle. The two cycles resulted in 2 products of engineering, which are a small-scale hydraulic lift in first cycle and a small-scale submarine in second cycle. The making of these products needs a good understanding of Newton's first and third laws of motion. Both products, respectively, are the application of the theory of Pascal's Principle and Buoyancy and Archimedes' Principle. By making products during learning, students can improve or fix

their retention of long term information [59]. Besides, the finishing of these engineering products force the students to be active in communicating their conceptual understanding to their peers through STEM education [60]. During learning, an active student can train their scientific reasoning in building their critical thinking skills [56]. This finding supports the result of previous study which found that STEM approach in Physics learning can yield positive response of satisfaction and produce better critical thinking skills better than the class which was taught without STEM approach [61]. It's clear that STEM-LC model results in better CTA in students than LC model.

STEM-LC model is more effective than LC in building students' CTA. Few of the activities in STEM-LC model were indeed not done in LC model. Few of those activities are the presentation of few examples of technology as the form of application of concept or theory in learning, the activity of making engineering product in learning by students, and the activity of making poster and written report relating to the engineering product. This is what suspected as the cause why the increase of N-gain in STEM-LC model class is higher than LC class. However, both classes are successful in gaining the increase which is higher than the N-gain threshold at the value of 0.48, which is the value of the average of N-gain which is able to be obtained in learning which involve students who are active in its activity [62].

Consecutively, the post-test data of Experiment and Comparison classes are analyzed with Cohen's d-effect size. The result of the measurement of the strength results in the value of d-effect size of 0.603 (medium category). This means that the field practice of the STEM-LC method in schools had a medium impact than the LC method in increasing students' CTA.

#### 4. Conclusion

This research has these followings conclusions. Experiment class and Comparison class have significantly higher post-tets score than pre-test score and have N-gain value in high category. This means that both models, STEM-7E LC in Experiment class and 7E LC in Comparison class, were effective in building students' CTA. Both classes have significantly different pre-test data, which leads to the transformation of the data as covariate variable. After the pre-test data is controlled, it is found that the enhancement in students' skill was affected by the different initial state and the different treatment of learning. However, both are independent of each other. STEM-LC model results in significantly better construction of students' CTA than LC model. However, STEM-LC model was more effective than LC in building students' CTA. The field practice of the STEM-LC method had a medium impact than the LC method in increasing students' CTA. It is recommended for future research to add the religious and art aspects in STREAM approach in an effort to built better CTA in students.

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