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# Science, technology, engineering, and mathematics (STEM) based learning of physics to develop senior high school student's critical thinking

D Yulianti, Wiyanto, A Rusilowati, S E Nugroho and K I Pangesti

Physics Department, Faculty of Mathematics and Science, Universitas Negeri Semarang

\*Corresponding author: yulifis04@yahoo.com

**Abstract.** The purpose of this research is to know the development of senior high school student's critical thinking skills through Science, Engineering, Technology and Mathematics (STEM) based learning physics. The critical thinking indicators developed in this study include hypothesizing, interpreting, analysing, summarizing and evaluating. Design of this research uses One Group Pretest-Posttest Design. Subjects in this study were 2nd grade of Senior High School Students, from three Senior High School in Semarang City. The results showed that discussion, experiment, project making and presentation activities that were packaged in STEM based physics learning could develop critical thinking skills in aspects of hypothesizing, interpreting, analysing, summarizing and evaluating. The result of the gain test shows the development of hypothesis, analysing, and evaluating ability included in high category, while the ability to interpreting and summarizing is included in the medium category.

## 1. Introduction

The results of Trends in International Mathematics and Science Study (TIMSS) for secondary school students show that the Indonesian students' scores in math and science are still below the standard average score of 500. The math and science average scores obtained by Indonesian students amounted to 386 and 406 [1]. Besides showing low learning outcomes, the results of that study also illustrate the critical thinking skills of Indonesian students. [2] study shows that questions or problems used in the TIMSS can be used to measure higher-order thinking skills such as critical, practical, and creative thinking skills. Thus, students who couldn't solve the TIMSS problem indicated that high order thinking skills such as critical thinking is still low.

The ability to think critically is an important skill for students, especially in studying physics. Students who have the ability to think critically can learn physics better [3]. To learn content it is essential to think analytically and evaluative, a critical thinker can be able to acquire knowledge, understanding, insights, and skills in any given body of content [4]. All these aspects illustrate the intellectual resources needed for completing every challenge in studying sciences.

Some developed countries, such as the United States and Australia, adapt to 21st century capabilities through the development of STEM (Science, Technology, Engineering and Mathematics) education. The ability of the 21st century mentions the ability to personalize, self-management, communicate, critical thinking, and problem solving. Based on [5], integration of science, engineering, and mathematics can develop critical thinking skills.



The purpose of physics learning as outlined in the framework of the 2013 curriculum is to master the concepts and principles of physics, and to develop science and technology. One of the applied physics concept that contribute greatly to the latest technology is dynamic fluid. According to contents of the 2013 Indonesian curriculum, students' understanding of the application of dynamic fluid in technology is one of the competencies that must be mastered by students. The integration of science, technology, engineering, and mathematics is expected to support those competencies. The purpose of this research is to know the development of senior high school student's critical thinking skills through STEM-based learning.

## 2. Methods

This research uses One Group Pre-test - Post-test Design. Subjects in this study were 2nd grade of Senior High School Students, from school of three Senior High School in Semarang City. The data collection in this study used essay test to measure the development of critical thinking ability. The essay test is based on five critical thinking indicators, i.e. 1) hypothesis 2) interpreting 3) analysing 4) summarizing and 5) evaluating [6].

The development of critical thinking ability is calculated by finding the percentage of scores obtained on each indicator of critical thinking compared with the maximum score. The development of critical thinking ability was analysed using gain test. The significance of the development of critical thinking ability is analysed using the t-test.

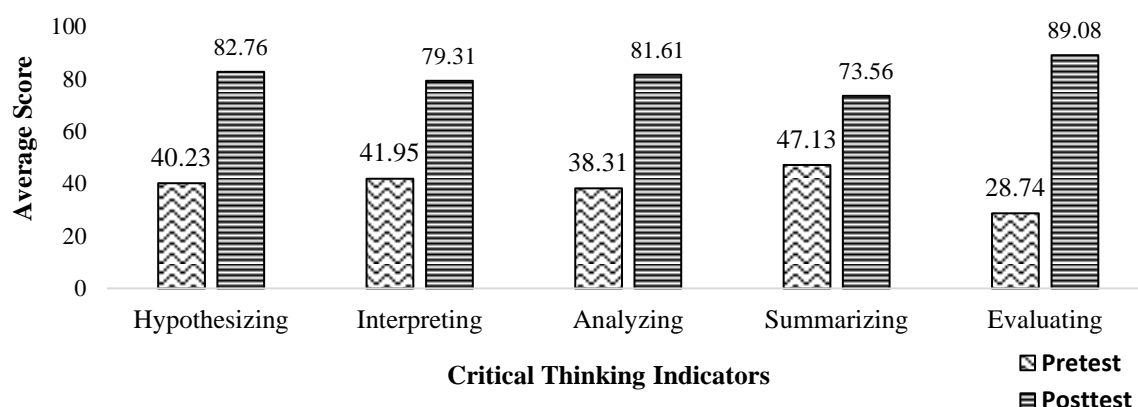
## 3. Result and Discussion

STEM-based learning integrates science, technology, engineering, and mathematics to train students to apply basic content of STEM in everyday life [7]. In STEM-based physics learning, physics concepts are taught through the approach of science, technology, engineering, and mathematics to achieve physics learning goals. It can improve motivation, provide experience in the engineering process and improve student achievement [8].

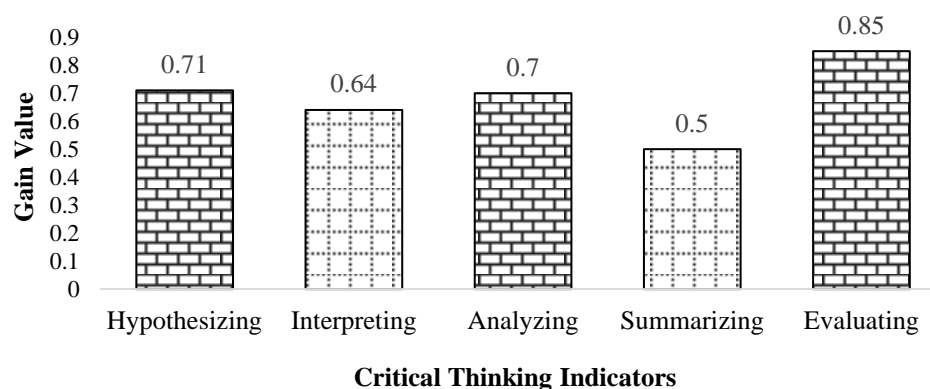
STEM-based learning in this research integrates physics concepts with technological, engineering, and math concepts. The concept of physics as a part of science is contextually conveyed through its application in technology and engineering. The integration of technology and engineering into the learning process can develop high-order thinking skills, attract students, and master the concept of science [9,10]. Mathematics concept in STEM-based learning helps students optimally understand the physics concept. Mathematics as the language of science and technology can give a sense of meaning in something, so that easily to understand [11].

STEM-based learning is carried out through a series of activities beginning with introducing basic competencies as well as learning objectives. It is aimed students can understand the expected result after studying the learning content. Each beginning of the sub chapter, students are directed to discuss questions as well as literature related to dynamic fluids. Furthermore, students study the subject matter in each sub-chapter. At the end of the learning, students are asked to solve problems or questions related to dynamic fluid. Students are also required to carry out experiment and project-making activities in accordance with the procedures. Thus, students can receive the learning content well through discussion, experiment, project-making and presentation. According to [12] study STEM-based learning improve the learning experience, thereby growing creativity, curiosity and encouraging cooperation among students. Activities undertaken during the learning process also attract students' interest. Learning through observation and practice create pleasant situation and implicate on improving learning outcomes [13].

The development of critical thinking skills is assessed through essay test. The result of pre-test and post-test analysis of each indicator of students' critical thinking ability is presented in Figure 1. Pre-test and post-test result data are also analysed using gain test. The gain value of each indicator of students' critical thinking ability is presented in Figure 2.



**Figure 1.** Pretest and posttest average score of critical thinking indicators



**Figure 2.** Gain value of critical thinking indicators

Based on the analysis of the ability of critical thinking, STEM-based learning can develop critical thinking ability. That result proves that STEM's integrative approach has a positive impact on student learning especially on increasing learning achievement and developing critical thinking skills [14, 5].

The STEM aspects poured into learning support the development of critical thinking skills. [15] state that learning associated with aspects of STEM develop significant critical thinking skills. The development of critical thinking ability is also supported by the problems encapsulated in the form of discussion questions. The problems presented are tailored to the STEM aspects and facilitate the students to discuss to find each problem solving. Problem-based learning activities in STEM-based learning are innovative and exciting for the learners. It will spark motivation to pursue more advanced math and science courses [16].

The activity procedures presented in STEM-based learning, such as practicum and project-making activities, can also encourage the development of critical thinking skills. Practical activities as well as project-making provide real experience for students to apply the physics concept. It can be used as a basis for solving problems that require critical thinking. According to [17] research, experiment activity gives positive influence to the development of critical thinking ability.

The development of critical thinking ability is influenced by many factors. Besides the factors associated with the teaching process, the development of critical thinking skills is also influenced by other factors, such as the personal condition and background of each student [18]. Viewed from the psychological side, students in the 12 to 18 year age range (adolescents) have reached formal operational stage which is the last stage in the hierarchy cognitive development. According to [19],

adolescence is an important transitional stage in the development of critical thinking. This is supported by the study of grade 4th, 8th and 11th students who stated that critical thinking skills continue to grow with age. The development of critical thinking ability can reach 43 percent when students are in 11th grade. However, the results also state that basic skills such as literacy and mathematics skills do not develop during childhood, the ability to think critically impossible to reach maturity in adolescence.

### *3.1. Hypothesizing*

The ability of hypotheses is developed through activities that stimulate students to make temporary estimates of the causes of a problem. Students are asked to answer questions that encourage students to observe various phenomena, so as to draw a conclusion. [20] states that prediction results related to the ability for observing, classifying, and summarizing.

A real activity carried out in the classroom, students are asked to observe some images related to the characteristic of the ideal fluid. Students discuss and predict ideal fluid characteristic based on pictures or illustrations so that they can draw conclusions about ideal fluid characteristic. The pictures help students predict the occurrence of a phenomenon, so that they are able to understand the concept of the occurrence of the phenomenon. The illustrative pictures presented with the text can add to the student's learning experience [21]. In addition, the integration of STEM aspects into illustrative pictures presentation also enriches the student's learning experience. STEM-based learning has been shown to increase learning content by stimulating students' ability to transfer knowledge [22].

The ability of hypotheses is also developed through experiment activities. Practical activities encourage students to formulate hypotheses before conducting an investigation through a simple experiment. In addition, practicum activities can facilitate students to observe directly the application of a physical concept. Through these activities students also gain experience that can be used to solve problems. [23] mentioned factors that can influence the ability to hypothesis is an understanding of the concept and the relationship between variables in a practical activity.

### *3.2. Interpreting*

The ability to interpret is developed through practicum activities. STEM-based learning facilitates students to carry out practicum activities according to procedures, so that students can conduct an inquiry to obtain data or information. The activity guides students to interpret the results of the lab data in the form of tables and graphs. [24] research results revealed that practicum activities carried out in accordance with the procedure can improve the ability to interpret significantly. In addition, other factors that affect the ability to interpret are the understanding of students' concepts of the material being studied. In accordance with the research of [25], the ability to interpret is influenced by conceptual understanding.

The average increase in values on the interpretive aspects of data that are still relatively moderate can be attributed to the lack of activities that facilitate students in using tables or graphs. According to [26], graphs with verbal cues in the form of texts provide direction on how and when to check referral charts can make the science text more useful. The use of graphs can also be a means of training students' ability in understanding the information presented in non-text form. According to [27], the ability to interpret graphs (interpreting data) is influenced by students' understanding of complex concepts and information presented simultaneously in a graph.

### *3.3. Analyzing*

Analyzing is the activity of elaborating complex topics or substances into simpler elements. [28] stated that terms such as observing and analyzing or interpreting do not refer to mental operations, but to the activities undertaken. Analyze activities can only be assessed when a person has produced an analysis of a topic or problem. Analytical skills are needed in the troubleshooting process. According to [29], critical thinking is a well-organized mental activity in making problem-solving decisions by analyzing and interpreting data. The contextual issues presented in STEM-based learning motivate students to

find solutions according to the stages of thinking ability. The ability to think critically is stimulated when students analyze a problem by looking for reasons or evidence that supports their idea to solve the problem. Lessons that present problems related to the material being studied can improve student activeness and high-level thinking skills, such as analytical skills [30][31].

### 3.4. Summarizing

STEM-based learning supports the development of students' skills in concluding through discussion questions given in each sub-chapter. These questions encourage students to observe various phenomena, thus obtaining various information as a basis for drawing conclusions. In addition, the content of materials and information received by students during the learning process also supports the development of students' skills in concluding. In their research, [32] stated that students draw conclusions based on data or information received by them. Students can draw a conclusion if they have a deep knowledge of the material being studied. However, the average increase in value on the assimilating aspect is still moderate. This may be due to some information conveyed through illustrative drawings. Students can obtain information if they are able to interpret the messages conveyed by the images. The limited information received by students due to the not optimal ability to interpret, develop the ability to attract a conclusion becomes less than optimal. In accordance with the opinion of [33], conclusions are influenced by the ability of students to synthesize pieces of information and integrate them into a single meaningful entity.

### 3.5. Evaluating

Evaluating ability is developed through discussion activities. STEM-based learning facilitates students to conduct discussion activities through questions given to students. Students are asked to provide an assessment to test a statement or phenomenon on the concept of physics. Discussion activities encourage students to take responsibility for solving their own problems. Through discussion activities students can share with other students to evaluate each other's evidence and arguments in solving problems [34]. In addition, discussion activities can also help students find problem solving related to the material being studied obtained by students in the learning process used as the basis of consideration in arguing during the discussion process. Based on [31] research, the ability to evaluate can develop through problem-solving activities.

STEM-based physics learning is designed by including evaluation activities at the end of each lesson. Students are required to review the learning materials they have obtained at the end of each meeting and the end of each sub chapter. Evaluation activities can provide opportunities for students to reflect on learning individually or in groups [35].

## 4. Conclusion

STEM-based learning provides opportunities for students to carry out discussion, practicum, project-making and presentation activities that can stimulate the development of students' critical thinking skills. STEM-based physics learning leads students to understand the physics concepts that integrated science, technology, engineering, and mathematics so as to optimize the achievement of physics learning objectives, especially on dynamic fluid materials. Critical thinking skills that can be developed in this research include: to hypothesize, interpret data, analyse, conclude, and evaluate. The result of the gain test shows the development of hypothesis ability, analyse, and evaluate included in high category, while the ability to interpret data and conclude is included in medium category.

Suggestions that can be given for further research is to increase activities that can enrich the experience of students in digging information from tables, graphs, and images, in order to develop the ability to interpret and conclude more optimal.

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