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Developing of students worksheets through STEM approach to train critical thinking skills

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Abstract. Research has been carried out with the aim of producing student worksheets using the Science, Technology, Engineering, and Mathematics (STEM) approach to train students' critical thinking skills that are appropriate to be used in the learning process. The specific objectives of this study are to describe: 1) the validity of worksheets, 2) practicality of worksheets, 3) effectiveness of worksheets, and 4) achievement of critical thinking skills of students. This type of research is research and development with analyze, design, development, implementation, and evaluation (ADDIE) model. The trial subject in this research is 36 eleventh grade students of public high school in Banjarmasin city. The research instrument were the student worksheets validation sheet, the implementation sheet of the lesson plan, the learning outcomes test, and the observation sheet of critical thinking skills. The results showed: 1) the student worksheets developed was categorized as valid, 2) the practicality of student worksheets was categorized as very practical, 3) the effectiveness of students was categorized as medium, and (4) achievement critical thinking skills of students was categorized as sufficient. It can be concluded that, the student worksheets through the STEM approach to train students' critical thinking skills was appropriate to be used in learning.

1. Introduction

In the 21st century, the development of science and technology is very rapid. Indonesia should be able to compete globally among developed countries. Therefore, education development in Indonesia can refer to the international education framework. 21st-century skill framework is one of many frameworks, which prioritize the learner to master science, studying skill, innovation, and skill in the field of information and technology.

Program of International Student Assessment (PISA) survey released in 2015 showed that Indonesian Education in the field of science is in the rank of 64th from 72 Organization for Economic Cooperation and Development countries [1]. This shows that the quality of Indonesian education is still low compared to other countries. If this situation is neglected, it will cause low-quality graduates. Countries around the world in a global era need graduates who have the ability of Science, Technology, Engineering, and Mathematic (STEM) that can compete globally and creatively solve problems [2,3].



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One of the innovations in education needed to face global challenges is integrating the STEM approach in learning [4]. STEM education can also be defined as a learning approach between two or more STEM components [5,6]. STEM learning can train students to apply knowledge in making the design as a form of problem-solving related to the environment by utilizing technology [7]. The center of various aspects or STEM activities is involving students in defining and formulating solutions to authentic problems in the real world [8].

One of the promising approaches to promoting critical thinking is STEM education [9,10]. The critical thinking is not only the process of applying concepts, experiments but also making a product or work [11]. The study of [12] states that students' scientific literacy can be built and improved if the learning process continues to practice thinking skills as needed in implementing 6E learning with STEM-based. The critical thinking of students with STEM education have sufficient critical thinking skills to criticize plans that have been systematically compiled themselves and give critics who build real problems faced [13].

Based on the results of tests of critical thinking skills in the eleventh grade of science in one of the public schools in Banjarmasin showed that students' critical thinking skills were still not trained. These results can be seen from the indicators of skills in formulating questions and answers, which categorized as low, indicator analyzing and reporting the results of experiments is categorized as sufficient, drawing conclusions, determining the action and formulating alternative solutions are categorized as low.

Based on the observations on the teaching materials used in the school, the student worksheets used are worksheets available in the textbook. The student worksheets contain a summary of subject matter and questions, not presenting contextual material related to STEM. The questions contained in the student worksheets can be answered easily from looking at the material included in the student worksheets. This causes students' critical thinking skills to be lacking trained.

To train the critical thinking skills of learners, a learning material that supports the process is necessary. This can be done by developing the student worksheets. The student worksheets is part of teaching material that serves to help students in the learning process [14]. In addition, the student worksheets must also be able to help students train their process skills and thinking skills, both creative, critical, and innovative thinking skills [15-17]. In this case, the student worksheets developed in this study is a student worksheets using STEM approach.

The material developed through this the student worksheet is Optical Tools materials. The choice of material is due to the application of the concept of material to many found in life. In addition, Optical Instrument material can be taught using the STEM approach to train critical thinking skills. Science in finding the concept, technology regarding the application of technology, techniques for making simple tools related to the matter, and mathematics to formulate mathematical equations and in terms of calculations. All these aspects are used to train critical thinking skills that give explanations, build basic skills, draw conclusions and set the strategy and action. Therefore research and development of the student worksheet is conducted with the STEM approach. The purpose of this study is to describe the feasibility of the student worksheets with the STEM approach to train students' critical thinking skills. It is expected that this research and development product, namely the student worksheets with the STEM approach can be used in the process of learning physics in High School.

2. Methods

The product developed is the student worksheet in Optical Equipment material. The development model used in this study is the ADDIE model. In the analysis phase, an analysis of students' critical thinking level, high school physics curriculum, and related theories and researches are carried out. In the design phase, the design of the student worksheets prototype I, three parts which are: 1) Eye, glasses, and camera; 2) run and camera; and 3) binocular. Then in the development phase, validation from experts and practitioners, conducted revision based on the results of validation, so that the student worksheet prototype II was obtained. In the implementation phase, product testing was conducted in high school, measuring the practicality of student worksheets, measuring the effectiveness of student worksheets,

and measuring the students' critical thinking. Last phase of evaluation, discussion about the advantages and disadvantages of the student worksheet and its' implementation.

The subjects of this study were 36 eleventh graders in one of the state high schools in the city of Banjarmasin. The research instrument were the student worksheets validation sheet, the implementation sheet of the lesson plan, the learning outcomes test, and the observation sheet of critical thinking skills.

The validity of the student worksheets was measured using a validation sheet which was assessed by two experts and one practitioner. The practicality was measured using the observation plan for lesson plans that was assessed by two observers. The effectiveness obtained from the results of the assessment of the answers of students in the pretest and posttest, which was analyzed using the N-gain score. The results of the analysis were then interpreted in the categories from [18]. Critical thinking skills were obtained from observation sheets of students in using the worksheets given. The categories of validity, practicality, and achievement of critical thinking skills using Widoyoko's criteria [19].

3. Results and Discussion

3.1. Analysis

In the preliminary research, the level of students' critical thinking at level grade XI at one of public high school in Banjarmasin city is in novice level. As one of the 21st-century skills, critical thinking play a crucial role in the future life of students [20,21]. Therefore, the learning process that emphasized critical thinking is urgent.

From the analysis of physics curriculum at high school level grade XI, one of the main basic competence is about optics. Basic competences of optics facilitate the learning process to enhance the critical thinking skill. The discussion about optics (basic competences 1 is analyzing the mechanism of optical devices using reflecting and refracting properties of light by mirrors and lenses) strongly related to science and mathematics concepts while the designing product that apply optics principles (basic competences 2 is making a work that applies the principle of reflection and/or refraction to mirrors and lenses) is related to engineering and technology. In consequence, the development of students' worksheet through STEM is suitable in optics topic.

3.2. Design

The products produced in the form of the student worksheets on the subject of optical equipment. The student worksheets arrangement has been adjusted to the characteristics of students and the characteristics of the optical equipment. The student worksheet developed consists of three student worksheets with different sub-topics for three meetings. The student worksheet 1 is for meeting 1 with subject matter eyes, glasses, and camera, worksheet 2 is for meeting 2 with sub-topics lup and microscope, and worksheet 3 is for meeting 3 with subject matter Binocular.

Each student worksheet contains the title, assignment instructions, time allocation, trial objectives, events in daily life related to the material accompanied by images to grow students' critical thinking skills, and assignments according to the STEM approach and indicators of critical thinking skills. The assignment section of the student worksheet has STEM components, namely: 1) Science by conducting experiments, 2) technology by application technology and experiments on simple technology, 3) techniques by making design and designing technological products, and 4) mathematics by solving mathematical problems. The STEM component contained in the worksheets is combined with the training of students' critical thinking skills.

3.3. Development

3.3.1. Validation Result

One component of the learning process is that the worksheet is categorized as valid if it can measure what should be measured. Validity is related to "accuracy" with measuring instruments [22]. Table 1 shows the results of the validity of the student worksheet.

Table 1 The Validity of Student Worksheet

Assessment Aspect	Score
Didactic	3.33
Constructive	3.44
Technical	3.30
Category	Valid

The arrangement of a good worksheet need to meet various requirements, such as didactic conditions, constructive conditions, and technical requirements [23]. Based on Table 1, it shows that the developed student worksheets have a valid category and can be tested on students in learning activities. According to teaching materials including valid worksheet can support the learning process. Implementation [24,25].

3.3.2. The Student Worksheets Practicality

Practical the student worksheets is an easy-to-implement the student worksheets, easy to check, and equipped with instructions so that other people can use the student worksheets. Practical means easy to use [18]. The practicality of the student worksheets can be measured in the implementation of learning that has been developed. Table 2 shows the practicality of the student worksheets.

Table 2 The Practicality of the student worksheet

Meeting	Score
First	3.52
Second	3.60
Third	3.82
Category	Very Practical

The student worksheets are categorized as very practical and can be used in the learning process. This is consistent with the opinion that learning tools are said to be practical if they meet the criteria that can be determined in accordance with the assessment of experts and the tools developed can be applied significantly in the learning process [25]. The implementation of lesson plans cannot be separated from the usage of the student worksheets that can facilitate students in the learning process so that the learning time runs systematically and efficiently. Students become more active and enthusiastic by using STEM the student worksheets. This is in accordance with our result, learning through STEM can increase student involvement, motivation, and problem solving skills [26-28].

3.3.3. The Student Worksheets Effectiveness

The effectiveness of the developed student worksheets can be seen from the test scores of students' learning outcomes. Based on the results of the analysis of the N gain obtained a value of 0.44 with the intermediate category. This finding shows that the student worksheet through STEM approach is effectively used in the learning process. Through STEM approach based on the student worksheets, students are given assignments in the form of experiments. In this activity, students are trained to conduct experiments, analyze and draw conclusions. In three meetings, students began to be trained in terms of conducting experiments, analyzing, and drawing conclusions. The next activity is technology, which is the application of technology by providing an explanation and application of technology to the material specified. Then, the mathematical problem-solving activities (mathematics) that perform calculations about the level of C3. The activity of designing a technology product (engineering) is to determine the steps/actions and to make a solution to the problem. In this activity, students are trained

to make a step/action and design a simple technological product with C6 level of problem. In addition, STEM learning has the potential to have a significant impact on students' lives, students have impressive experiences during learning and increase their motivation and interest in learning [6,29].

3.4. Attainment of Students' Critical Thinking Skill

The results of attainment achieving students' critical thinking skills can be seen in Table 3.

Table 3 Attainment of Critical Thinking Skill

Critical Thinking Indicator	Mean	Category
Giving Explanation	50,97	Sufficient
Formulating Question	42,36	Sufficient
Formulating Answer	47,64	Sufficient
Reporting Experiment Result	75,00	Good
Analyzing Experiment Result	44,03	Sufficient
Concluding Investigation Result	48,75	Sufficient
Concluding Calculation Result	54,24	Sufficient
Deciding Action	57,04	Sufficient

Students' critical thinking skills are measured from the observation sheet of critical thinking skills observed from the worksheet done by students. Then the data were assessed according to the rubric of students' critical thinking skills. Table 3 shows the attainment of students' critical thinking skills. All indicators of critical thinking skills are categorized as sufficient, unless the indicator of reporting the results of the experiment that is categorized as good. When compared, the critical thinking skills before being given with the STEM approach based student worksheet, there are several indicators that increase. This is consistent with the previous researches stated that integrating STEM aspects can have a positive impact on student interest, especially in terms of improving students' thinking [30,31]. STEM-based learning is can develop critical thinking skills, helping students in analyzing and solving problems that occur in real life. The problem is presented to encourage students to think deeply to solve the present problems. Through STEM education with project-based learning, students have sufficient critical thinking skills to criticize plans that have been systematically compiled by themselves and provide criticism that builds on real-life problems [10].

3.5. Evaluation

For further learning, learners should not only focus on one of the activities in the learning process such as exploratory activities because learning with the STEM approach is not only an investigation activity, but also about technology, engineering, and mathematics. This is based on a statement from NRC in 2011 which stated that STEM learning emphasizes several aspects of the learning process, namely technology, engineering, and mathematics [6, 32,33].

Moreover, before applying the STEM approach, the students must be trained in practical activities. Students must master the concept better, and be trained in collecting and analyzing data. Thus, the next STEM approach is not only easier to be applied to students but also supports the learning process in training students' critical thinking skills and improving student-learning outcomes. As has been revealed by several studies that STEM education can improve student learning outcomes and have a significant impact on student life [13,29].

4. Conclusion

It can be concluded that the developed the student worksheets through the STEM approach to train students' critical thinking skills was appropriate to be used in learning. This research has limitations, that the developed STEM approach based student worksheets is only limited to optical equipment material. Subject of trials are limited to one school. For further research, it is suggested to develop other material in physics learning and trials that conducted in several schools.

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