Instructional materials for optical matter based on STEM-CP (Science, Technology, Engineering, Mathematics-Contextual Problem) to increase student critical thinking skills in high school

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Abstract. The optical matter is divided into three different points of view; there are physical optics, geometric optics, and optical tools. Three different points of view make optical matter difficult to integrate. Besides, the learning of optical matter in school mostly focuses on formulas, not the concept, so students find it difficult to apply optical matter in their daily lives. Also, critical thinking skills are needed to apply a concept to solve problems in daily life. One of the solutions to these problems is to apply teaching materials that discuss concepts and mathematics in a balanced, integrated, equipped by a contextual problem to increase student's critical thinking skills and make it easier to apply optical concepts in daily life. One of the suitable teaching materials is optical teaching materials based on STEM-CP (Science, Technology, Engineering, Mathematics-Contextual Problem). This study aims to measure student’s critical thinking skills after implied optical teaching materials based on STEM-CP. This research used Quasi-Pretest-Posttest Experiment without control class. Data analysis using the mixed-method, and were analyzed quantitatively. The sample used was 33 students of class XI science. The result obtained from pretest and posttest with open questions following indicators of critical thinking skills. The application of optical instrument teaching materials and function based on STEM-CP showed that student critical thinking skills increase from weak and unacceptable to strong and acceptable.

1. Introduction

The optical matter is one of physical matter, which is essentially the study of nature and all phenomena that occur [1]. The optical matter is divided into three, namely physical optics, geometry optics, and optical tools. Physical optics discusses the four properties of light waves, namely dispersion, diffraction, interference, and polarization. Physical optics discuss the basic law of the properties of light waves. Geometry optics discuss refraction, refraction, and technologies in life that utilize light reflection and refraction. Optical tools discuss the tools that utilize optical geometry in life [2].

However, the optical matter is considered difficult because it has a high complexity when applied in everyday life [3]. High complexity arises because optical material has three different discussion perspectives and its difficult to integrate, thus impacting the difficulty of applying optical concepts in life. In addition to these obstacles, it turns out there are other obstacles that make optical material difficult for
students to digest. Moreover, many students consider that optical material is difficult because faced with many formulae [4]. It proves that the optical matter focused more on the mathematical study. The study of concepts and mathematic must be balanced so that students can apply optical concepts in life.

Application of concepts in daily life also requires good critical thinking skills. Critical thinking in a broader sense is the idea of scientific thought [5]. The critical thinking skills are the skills to think logically, reflectively, systematically, and productively which is applied to make judgments when making the right decision [6]. Therefore, we need the critical thinking skill to solve problem in daily life.

The solution to solving these problems is to apply teaching material in books that discuss the optical matter in terms of balanced mathematical and concepts, help combine the three material perspectives accompanied by problems related to concepts in life, and develop student's critical thinking skills. With this teaching materials, students will find it easier to understand optical concepts and their application and can solve problems related to concepts in life.

One of the teaching materials that are suitable and needed by students is teaching materials based on the STEM-CP approach (Science, Technology, Engineering, Mathematics-Contextual Problem). The STEM-CP approach is a refinement of the STEM approach that is complemented by a Contextual problem. The STEM approach is an integration of Science, Technology, Engineering, and Mathematics, which can link concepts and applications in daily life. The technical elements of the STEM approach can help students to explore student's mathematics and science and can develop a student's critical thinking skills. The STEM approach has a good impact to student learning outcome [7]. In addition, the STEM learning module can also improve student's science process skills [8].

Contextual problem is a problem in daily life that have function for stimulate the brain to arrange patterns that are realized into a concept [9]. Contextual problem is one way to make students motivated to learn because it provides real challenges to students, according to the concepts taught [10]. In addition, the benefit of contextual problems in learning are able to improve problem solving and critical thinking skills [11]. It can be said that contextual problem can make it easier to understand concept and train student’s thinking skills.

The STEM approach has a good impact on student learning outcomes [12], but it still cannot help students solve contextual problems using appropriate concepts. If the STEM approach is equipped with contextual problems (Contextual Problem) applied in teaching materials into STEM-CP based optical matter books, then these teaching materials can help students to understand optical materials in an integrated and apply optical concepts in life.

Based on the explanation above, this research was conducted to answer the questions: How student's critical thinking skills after implied the instructional materials for optical matter based on STEM-CP?

2. Methods
This research is quantitative research with one-group experiment design. The sample of this study was 33 students of class XI Science. Thirty-three students in one sample class were given a pretest about the optical matter to measure the level of student's critical thinking skills in early understanding. After that, students were guided by the teacher studying optical matter from teaching materials based on STEM-CP. STEM-CP based teaching materials are provided with the STEM approach. The teaching material is devoted to training student’s critical thinking skills.

Finally, students are given a posttest to measure their critical thinking skills after studying STEM-CP based optical teaching materials. Pretest and posttest questions consist of 4 open contextual questions that can measure student's critical thinking skills. There were six indicators of student's critical thinking skills measured, and those were interpretation, analysis, inference, evaluation, explanation, and self-regulation, with following explanations:
Table 1. The critical thinking skills indicators.

| Critical Thinking Skills Indicators | Explanation |
|-------------------------------------|-------------|
| Interpretation                      | Understand, express, and meaning of various experiences, situation, data, events, conventions, beliefs, rules, procedure, or criteria |
| Analysis                            | Identify the relationship between statements, questions, concept, descriptions, or forms of interpretation intended to express beliefs, judgements, experiences, reasons information, or opinion |
| Inference                           | Identify and secure the elements needed to draw reasonable conclusions, to form guesses and hypotheses, consider relevant information from data, reports, principles, evidence, judgements, beliefs, opinions, concept, descriptions, questions, or forms interpretation |
| Evaluation                          | The credibility of statements or other interpretations regarding a person’s perceptions, experiences, situations, judgements, beliefs or opinions, and has the logical power of the relationship between statements, descriptions, questions or forms of representation |
| Explanation                         | Reasoning in terms of evidence, conceptual, methodology, logical criteria, and contextual considerations at the time based on one result, and to present one reasoning in the form of convincing arguments |
| Self-Regulation                     | Self awareness to monitor one cognitive activities, the elements used in the activity, and the result after the activity, especially by applying skills in analysis and evaluation to self assessing with a view of questioning, communicating, validating, or correcting one of the reasons for result |

The data collection techniques used test and documentation method. Test method in the form of pretest dan posttest, and documentation method to collect the pretest and posttest score, student’s name data, and photos of activities.

The critical thinking skills data obtained from pretest-posttest scores, and analysed using the following criteria:

Table 2. The critical thinking skills criteria.

| Score | Critical thinking skills criteria |
|-------|-----------------------------------|
| 4     | Strong                            |
| 3     | Acceptable                        |
| 2     | Unacceptable                      |
| 1     | Weak                              |

Source: Facione, 2009 [14]
3. Results and Discussion

3.1. Instructional Material Based on STEM-CP

The STEM approach is one of the best priorities for school education in the world [15 & 16]. Learning using the STEM approach is learning that not only teaches theory but also practice in the form of projects so that students experience the learning process directly [17]. Through STEM, students can find innovative solutions to problems in daily life and can convey them well [18]. While contextual problems are problems in daily life that serve to stimulate the brain to arrange patterns that are realized into a concept [19]. Contextual problems make learning more directed because they begin with problems that students must solve, thus encouraging student's thinking skills [20].

STEM-CP based teaching materials have stages of contextual problems, Science, Technology, Engineering, and Mathematics. The contextual problem part at the beginning serves as a link between daily life and the concepts that will be discussed. The scientific concepts provided in this teaching material are self-construct concepts, so students look for themselves the optical concepts that underlie contextual problems, which are facilitated in practical activities. The technology part explains the application of science concepts in technology. The engineering part is a step for students to develop their concepts and technology in solving contextual problems early on. The mathematics part functions to help students in designing contextual problems in the engineering department.

The five parts of optical teaching materials based on STEM-CP are integrated with each other. Contextual problem are intentionally provided in this teaching material so that students more easily to understand the problem given. Optical problem in contextual problem come from environment of students about and most students have experienced the problem. Optical material in science part explain about concept of reflection and refraction of light, which is the basis for solving the contextual problem. The discussion of reflection and refraction of light is equipped with examples of application and practicum of concept proof. Optical material in technology part explain about the use optics in life, such as mirrors, lenses, and several optical devices that are often used such as eyes, glasses, cameras, magnifying glass, microscopes, and binoculars. Optical materials in engineering part contain a guide for students to create tools that can be a contextual solution to the problem. The guide includes instructions for making a tool design, an explanation of the tool used, how to manufacture, and a description of the finished tool. Optical material of mathematics part contain guidance to the use of mathematical calculation to test the tool design that have made and finished tool. At the end of the learning, there is a way of testing tool to prove the tool suitability to solve contextual problem that given at the beginning learning. All of parts in optic instrustional material based on STEM-CP is follow the STEM approach, that can increase the students critical thinking skills. Every steps in this instructional material is equipped with guidelines in developing students critical thinking skills, from interpretation (in contextual problem part), analysis and inference (in science and technology parts), evaluation and explanation (in engineering and mathematics parts), to self regulation (in engineering, mathematics, and proof parts).

3.2. Student’s Critical Thinking Skills

The quantitative data of student's critical thinking skills were obtained from pretest and posttest scores. Pretest and posttest consist of open-ended questions that correspond to indicators of critical thinking skills and contextual problems. The percentage of student's critical thinking skills scores in the pretest and posttest is presented in the following table and graph:
Table 3. Critical thinking skills of pretest and posttest answer students.

| Critical thinking skills criteria | Percentage of pretest | Percentage of posttest |
|----------------------------------|------------------------|------------------------|
| Strong                           | 6.64 %                 | 40.15 %                |
| Acceptable                       | 11.36 %                | 42.4 %                 |
| Unacceptable                     | 28 %                   | 12.1 %                 |
| Weak                             | 54 %                   | 5.35 %                 |

Figure 1. Critical thinking skills of pretest and posttest answer students.

This data shows that the pretest value of critical thinking skills of some students is in the weak category (54%), and some students are spread in three categories, there as unacceptable (28%), acceptable (11.36%), and strong (6.64%). This indicates that the critical thinking skills of students prior to the application of optical teaching materials based on STEM-CP are relatively low. However, after the application of optical teaching materials based on STEM-CP, the critical thinking skills of student is increase. This can be detected from the posttest score that given after treatment, which is 40.15% in the strong category, 42.2% in the acceptable category, 12.1% in the unacceptable category, and 5.25% in the weak category.

Based on these data, it showed that student's critical thinking skills were relatively low before learning using optical teaching materials based on STEM-CP, and increased after that. It proves that student's critical thinking skills can improve if they use STEM-CP based optical teaching materials. The increase that occurred was from a dominant pretest weak and unacceptable score to an acceptable and strong posttest dominant score. Because of the student's critical thinking skills increase, students can apply optical concepts to solve problems in life.

4. Conclusions
This research could be concluded that the critical thinking skills of most students increase from the weak and unacceptable to acceptable and strong categories. The largest percentage of critical thinking skills
before the application was 54% weak and 28% unacceptable. The largest percentage of critical thinking 
skills after the application was 42.4% acceptable and 40.15% strong. Increased critical thinking skills 
increase after students learn the material using STEM-CP based optical teaching materials. This 
 improvement is a sign that students can understand the concept deeply, as well as applying it to solve 
problems in daily life. Based on conclusion, we recommend the importance of developing student’s 
critical thinking skills to solve problem in daily life. For the future research, we suggest to analyze the 
student’s creative thinking skill using instructional material for optical matter based on STEM-CP.

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