



# The Effectiveness of Problem Solving-based Optics Module in Improving Higher Order Thinking Skills of Prospective Physics Teachers

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**Abstract:** This study aimed to identify the effectiveness of using physics-based problem-solving modules in improving prospective physics teacher students' higher-order thinking skills (HOTS). The experimental method has been used in designing the one Group Pretest-Posttest Control Groups. The research sample was all students who took the optics course. HOTS data was measured using a two-tier multiple-choice test instrument, and problem-solving ability data was measured using a Likert scale questionnaire. Data analysis was performed using descriptive and inferential statistics, including the N-Gain test, effect size, and Kruskal Wallis. The results showed that (1) there was an increase in student HOTS after the problem-solving-based module was applied by 0.42 in the medium category, and an increase occurred in all aspects of HOTS, including analyzing, evaluating, and creating; (2) the effect of problem-solving ability on students' HOTS; and (3) the effectiveness of problem solving-based modules is 2.36 in the very effective category. The results of the study can be concluded that the problem-solving-based optical module that has been designed is very effective in increasing students' HOTS and problem-solving abilities to support student success in learning optics.

**Keywords:** Optics; problem-solving; Modules; Higher-order thinking skills

## Introduction

In the physics education curriculum, students must take many courses, one of which is optics. The learning achievement of the optics course is being able to explain and apply the concepts of geometrical and physical optics in solving physics problems logically and critically, as well as verify various concepts of vibration and waves through responsible, independent, and measurable experimental activities. The concept of optics is essential to learn for prospective physics teachers because this concept is the basis for understanding subsequent materials such as modern physics and quantum physics. In addition, the optical subject is a material taught to high school students. As prospective physics teachers in secondary schools, students should understand optical content, both geometric and physical optics (Kaltakci-Gurel et al., 2016; Murtono, 2015). A good understanding of the content will make it easier for prospective physics

teachers to teach abstract optical concepts so that they can be transformed into language and learning that high school students easily digest.

Several studies show prospective physics teacher students' mastery of optics concepts is still low. Most students are still wrong in understanding ray diagrams to explain how objects look and how light propagates to the eye, the function of the observer in the process of forming and observing real and virtual images, and the function of the screen in the formation of images and the observation process (Galili & Hazan, 2000; Kaewkhong, 2020; Kaltakci-Gurel et al., 2016). Even research conducted by Goldberg & McDermott (1986) and Wosilait et al. (1998) found that most students had severe difficulties regarding the consequence of the nature of light that propagates in a straight line in one medium and then reflects and refracts when it encounters another medium.

Optical subject characteristics are abstract and complex to observe directly using simple tools, so high-

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level thinking processes are needed. Higher-order thinking skills (HOTS) are the ability or way of thinking logically or a person's reasoning process in solving a problem or problem. Many experts study the importance of HOTS. Tan & Halili (2015) asserted that HOTS is an important skill for future generations in facing the 21st century, so it needs to be instilled into prospective teacher students (Gonzales et al., 2017; Mumford et al., 2017; Utama et al., 2020). Moore & Rubbo (2012) revealed that HOTS has an important role in the problem-solving process, including critical thinking, in-depth analysis, synthesis, reflection, and creativity (Hashim et al., 2017; Saeed & Ahmed, 2021; Yuliati & Lestari, 2018). Therefore, HOTS involve cognitive processes, including analysis, evaluation, and creation. Students with good HOTS will have good reasoning, think critically, be creative in solving problems, and finally be able to make conclusions (N. Nurhayati et al., 2022).

However, the higher-order thinking skills of prospective physics teachers are still not as expected. The results of the analysis of student answers conducted by Nurhayati & Angraeni (2017) show that students completing the final semester exam questions on optical material are still low for HOTS criteria questions. Only 20% of students can solve problems at a high level, such as analyzing, evaluating, and creating. Erfan & Ratu (2018) found that most of the prospective physics teacher students were able to solve problems in the low order thinking (LTS) category but were still dominant in the low category on higher-order thinking skills (HOTS). Therefore, it is necessary to change the learning process to improve students' high-level skills to make it easier for students to understand an abstract optical subject.

A person with high-level thinking can associate newly known information with previously owned information by connecting the two pieces of information to form a concept that is used in solving problems from a difficult situation (Lewis & Smith, 1993). Therefore, in stimulating the process of connecting new information and information previously owned by a person, it is necessary, to begin with, a problem or question that must be resolved (Erfan & Ratu, 2018). This learning process is known as problem-based learning (PBL).

PBL is innovative learning used to practice problem-solving skills through real experience (Baker, 2000; Rideout, 2001). PBL is an innovation in learning because, in PBL, students' thinking abilities are optimized through a systematic group or teamwork process so that students can empower, hone, test, and develop their thinking skills on an ongoing basis. Problem-based teaching is a very effective strategy for teaching higher-order thinking processes (Anazifa & Djukri, 2017; Khoiriyah & Husamah, 2018; Shishigu et al., 2018; Tan, 2003). This effect can be seen in several studies that apply PBL and are proven to improve

students' thinking skills. (Nurhayati et al., 2021; Nurhayati et al., 2021) found that the HOTS of prospective physics teacher students could be increased through PBL learning. The research of (Shishigu et al., 2018) shows that students who are taught using the PBL model can apply the principles of physics (conceptual approach) better than those taught through conventional learning. PBL helps students identify the relationship between theory and practice, increases student motivation to learn, and eliminates rote memorization so that students can understand essential concepts, principles, and theories in physics.

Learning modules become learning materials that play an essential role in teaching and learning physics. Modules as suitable learning materials must be packaged comprehensively and systematically, including planned learning activities designed to help students understand specific learning objectives. The use of modules in physics learning has been proven to improve students' scientific literacy skills (Mustakim et al., 2020), cognitive learning outcomes (Fatmi et al., 2021), and critical thinking skills (Wahyuni et al., 2017). Based on observations and interviews with several students, it is known that the teaching materials used in optics courses are still limited to textbooks. Students said that the teaching materials used were quite challenging to understand the concept of optics. Therefore, in this study, PBL was applied through problem-solving-based learning modules in physics problem-solving abilities. Research on modules with problem-solving is still rarely done. Problem-solving-based modules are currently an alternative to physics learning that can build generations to face the challenging 21st century.

## Method

The pre-experimental method has been used in this research (Babbie, 2016; Kumar, 2011; Marczyk et al., 2006). The design of the current research scheme is shown in Figure 1.

The sample in this study was selected by intact group sampling, namely all students of the physics education study program who took the optics course, which consisted of one class. Test and indirect communication techniques were used in collecting research data. The test technique was used to measure students' HOTS, and the questionnaire used a closed questionnaire to measure physics problem-solving ability. Two types of instruments are used, namely; (1) 12 items of higher-order thinking multiple choice with reasons and given before and after learning using problem-solving-based modules (Figure 2); (2) a closed physics problem-solving ability questionnaire using a checklist. The measured aspects of problem-solving include recognizing problems, planning, implementing,

and evaluating solutions. All of the instruments used in this study had high validity and reliability criteria.

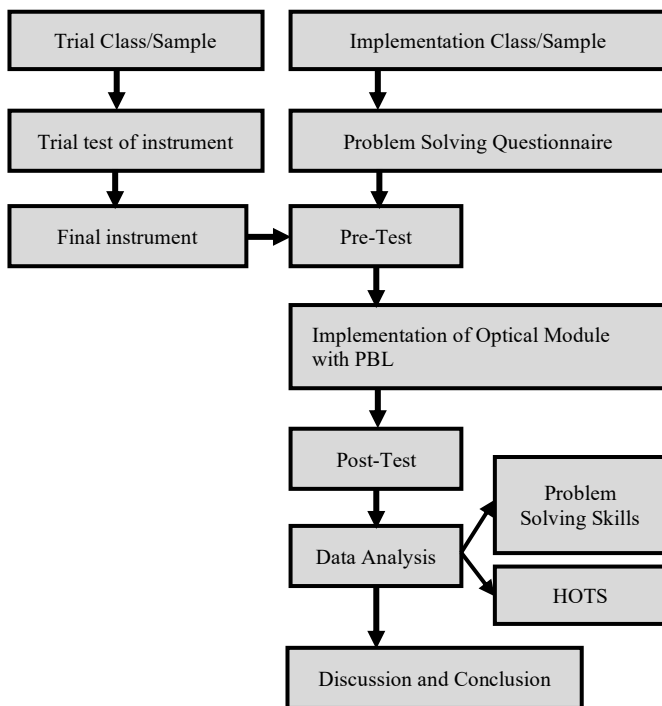


Figure1. Current Research Scheme

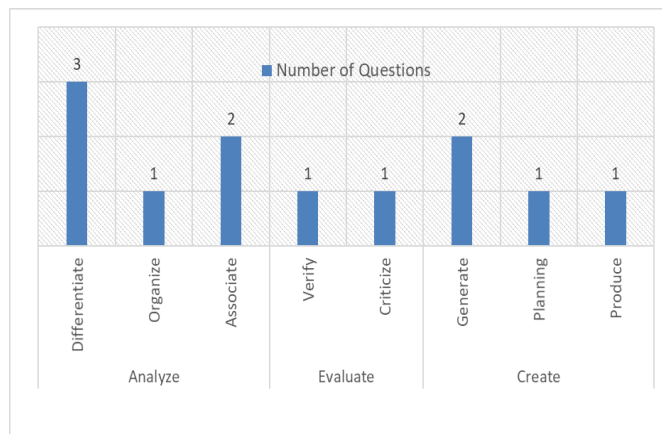


Figure 2. Distribution of HOTS Test Items

Data analysis was performed using non-parametric statistical tests and descriptive statistics. Prerequisite data analysis tests include the data normality test with Kolmogorov-Smirnov and the data homogeneity with the Levene test (Mooi et al., 2018). Hypothesis test using Kruskal Wallis test (Cohen et al., 2018). All test statistics were calculated using IBM SPSS Statistics for Windows, Version 20.0. The significance value of hypothesis testing less than 0.05 was considered statistically significant. Descriptive statistics include normalized gain (Hake, 2007) and the effectiveness of using effect size or Cohen-*d* formulas (Kraft, 2020; Lipsey et al., 2012).

Table 1. Interpretation of Module Effectiveness

Effect Size	Interpretation
$d < 0.2$	Very Small
$0.2 \leq d < 0.5$	Small
$0.5 \leq d < 0.8$	Medium
$0.8 \leq d < 1.0$	Big
$d \geq 1.0$	Very Big

Table 1 presents the interpretation of the effectiveness of the module. After statistical analysis, a qualitative evaluation was conducted to identify students' HOTS for each level.

## Result and Discussion

The results of the analysis prerequisite test, including the normality test and the homogeneity test of the data, are presented in Table 2. Based on the normality test of the data using the Kolmogorov-Smirnov test, it is known that the pre-test data has a calculated significance value of 0.200 or greater than the significant level =5% ( $> 0.05$ ), so that the pre-test data is normally distributed. In comparison, the post-test data has a calculated significance value of 0.012 or less than the significant level = 5% ( $< 0.05$ ), so the post-test data are not normally distributed. While the data homogeneity test results, it is known that the significance value of the calculation is 0.650 or greater than the significant level =5% ( $> 0.05$ ) so that the pretest-posttest data is homogeneous.

Table 2. Results of Data Analysis Prerequisites

Data	Based on	Significance Value	
		Kolmogorov-Smirnov Test	Levene Test
HOTS	Pre-test	0.200	0.650
	Post-test	0.012	

The research hypotheses include: (1) there is an effect of the application of problem-solving -based modules on students' HOTS; and (2) there is an effect of physics problem-solving ability on students' HOTS. Therefore, the data were not normally distributed, so the hypothesis test was carried out with non-parametric statistics. Table 3 presents a recapitulation of the results of hypothesis testing using non-parametric statistics.

Table 3. Research Hypothesis Test Results

Uji	Sig.	Decision
Hypothesis 1	0.003	Ho rejected
Hypothesis 2	0.030	Ho rejected

In Table 3, it can be seen that the results of hypothesis testing have a significance value of less than 0.05. This result means that Ho has been rejected and Ha has been accepted. The decision means: (1) there is an effect of the application of problem-solving-based

modules on students' higher-order thinking skills; and (2) there is an effect of physics problem-solving ability on students' HOTS. Based on the results of normalized gain, it is known that the increase in HOTS of prospective physics teacher students after the problem-solving-based learning module is applied with moderate criteria (0.42). The data on the percentage of student HOTS based on the HOTS criteria by (Prasetyani et al., 2016) is presented in Table 4.

81 - 100	Very good	0.00	0.00
61 - 80	Good	0.00	81.80
41 - 60	Enough	90.90	18.20
21 - 40	Deficient	9.09	0.00
0 - 20	Poor	0.00	0.00

Table 4 shows that there was a change in students' HOTS abilities after problem-solving-based modules were applied. It can be seen that before the module was applied, most of the students had HOTS in enough category, and after the module was applied, most of the students increased their HOTS in the good category. However, no students have HOTS in the very good category. If we look at each aspect of HOTS, it can be seen that there is a category shift base on pre-test and post-test data (Table 5).

**Table 4.** Percentage of Student HOTS Based on Criteria

Interval	Category	Percentage (%)	
		Pre-test	Post-test

**Table 5.** Percentage of Student HOTS each HOTS Aspect

Aspect	Percentage of Each Category (%)									
	Very Good		Good		Enough		Deficient		Poor	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Analyze	0.00	0.00	0.00	81.80	72.73	18.18	27.27	0.00	0.00	0.00
Evaluate	0.00	0.00	9.09	45.45	72.73	45.45	18.18	9.09	0.00	0.00
Create	0.00	0.00	0.00	18.18	9.09	63.63	90.90	18.18	1.00	0.00

Changes in prospective physics teacher students' higher-order thinking skills occur in analyzing, evaluating, and creating aspects. The pre-test results showed that 1.00% of students are in the poor category for creating, and after the problem-solving-based module is applied, there are no students in the poor category. The percentage of students in the poor category also experienced a decrease in all aspects of HOTS. Even in the analysis aspect, no students were in the poor category. However, most of the students are still in the less category for the aspect of creating. The percentage of students in the moderate category also experienced a decrease in the post-test. Students experienced a shift in the HOTS category from enough to good, so there was an increase in the number of students in the good category.

The effectiveness of problem-solving-based modules using effect size formula, is overall obtained d of 2.36 with a very effective category. The result means that problem-solving-based modules effectively increase students' HOTS in optics subjects. When viewed from each aspect of HOTS, problem-solving-based modules effectively increase students' HOTS for each aspect (Table 6).

**Table 6.** The Effectiveness of Using Problem-Solving-based Modules in Improving Student HOTS

HOTS Aspects	d	Criteria
Analyze	2.15	Very Big

Evaluate	1.09	Very Big
Create	6.04	Very Big

Based on the results obtained, it can be concluded that using problem-solving-based modules effectively increases the HOTS of prospective physics teacher students. These results are reinforced by previous studies that problem-based learning can facilitate students in developing higher-order thinking skills. It also develops knowledge, problem-solving and intellectual skills, teaches to share through involvement in authentic experiences and develops effective self-directed learning skills (Anazifa & Djukri, 2017; Khoiriyah & Husamah, 2018). The most significant increase in HOTS was after the problem-solving-based module was implemented in analyzing and evaluating. Problem-solving-based modules that are systematically designed can help students develop problem-solving (Nurhayati, Wahyudi, Saputri, et al., 2021), thus causing high student HOTS (Nisak et al., 2018).

The learning activities in the module are packaged step by step so students can easily follow the step. The stages of learning activities first presented the competencies and expected learning objectives. In the second step, students are asked to observe in the "Let's Observe! (*Ayo Kita Amati!*)" column. In this column, the phenomena that occur in everyday life are presented. Students are asked to observe these phenomena and then formulate the problems in the observation process in the second step. The problem formulation is then written in the "Let's Ask the Question! (*Ayo Kita Menanya!*)" column. In this step, students are trained to

be careful in observing and able to present problems found from the phenomena and data presented. In stimulating students to find problems with phenomena,

this column also presents examples of problem formulations so that students indirectly begin to hone their thinking skills in analyzing existing problems.

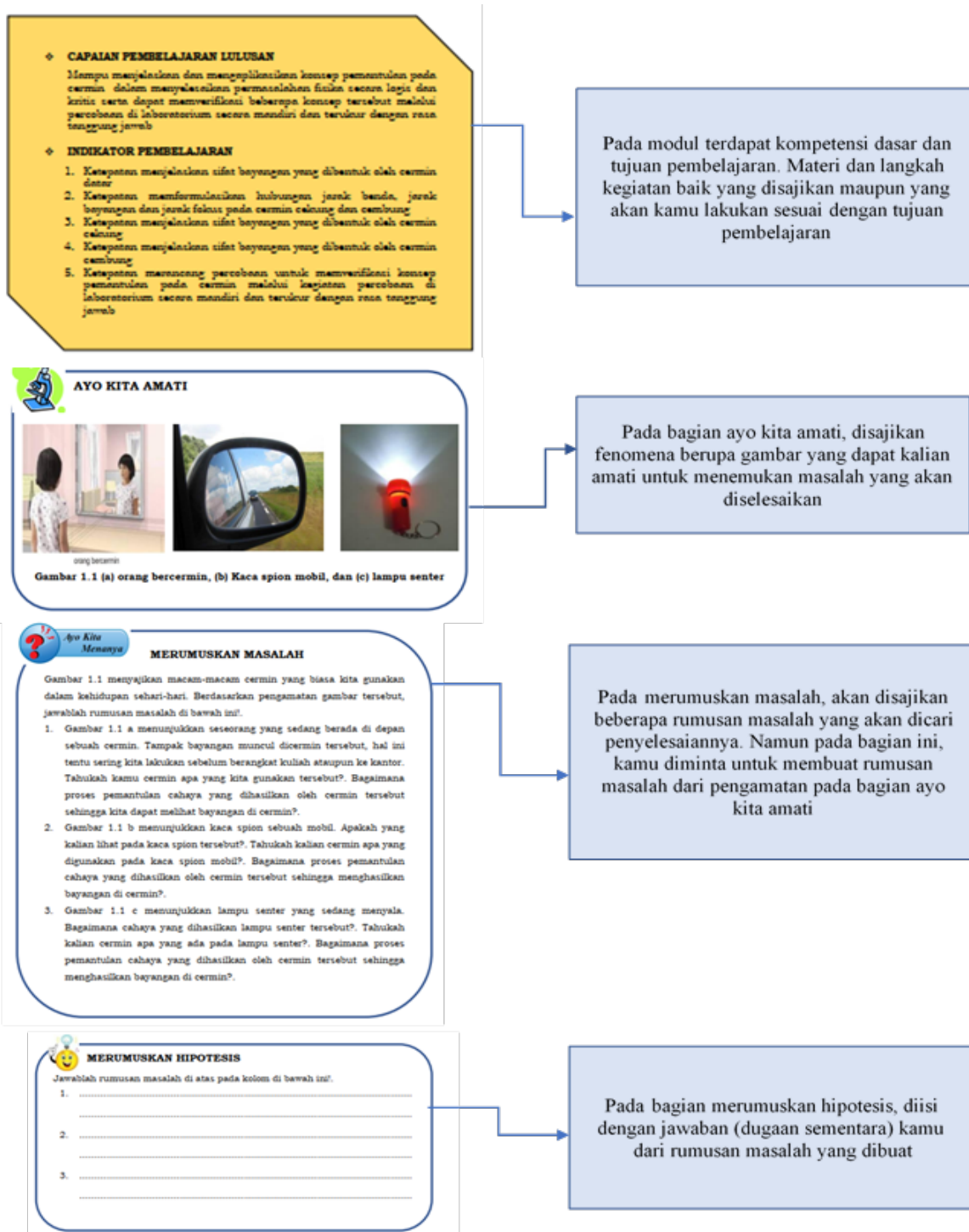


Figure 3a. Activity Steps in a Problem-Solving-Based Module

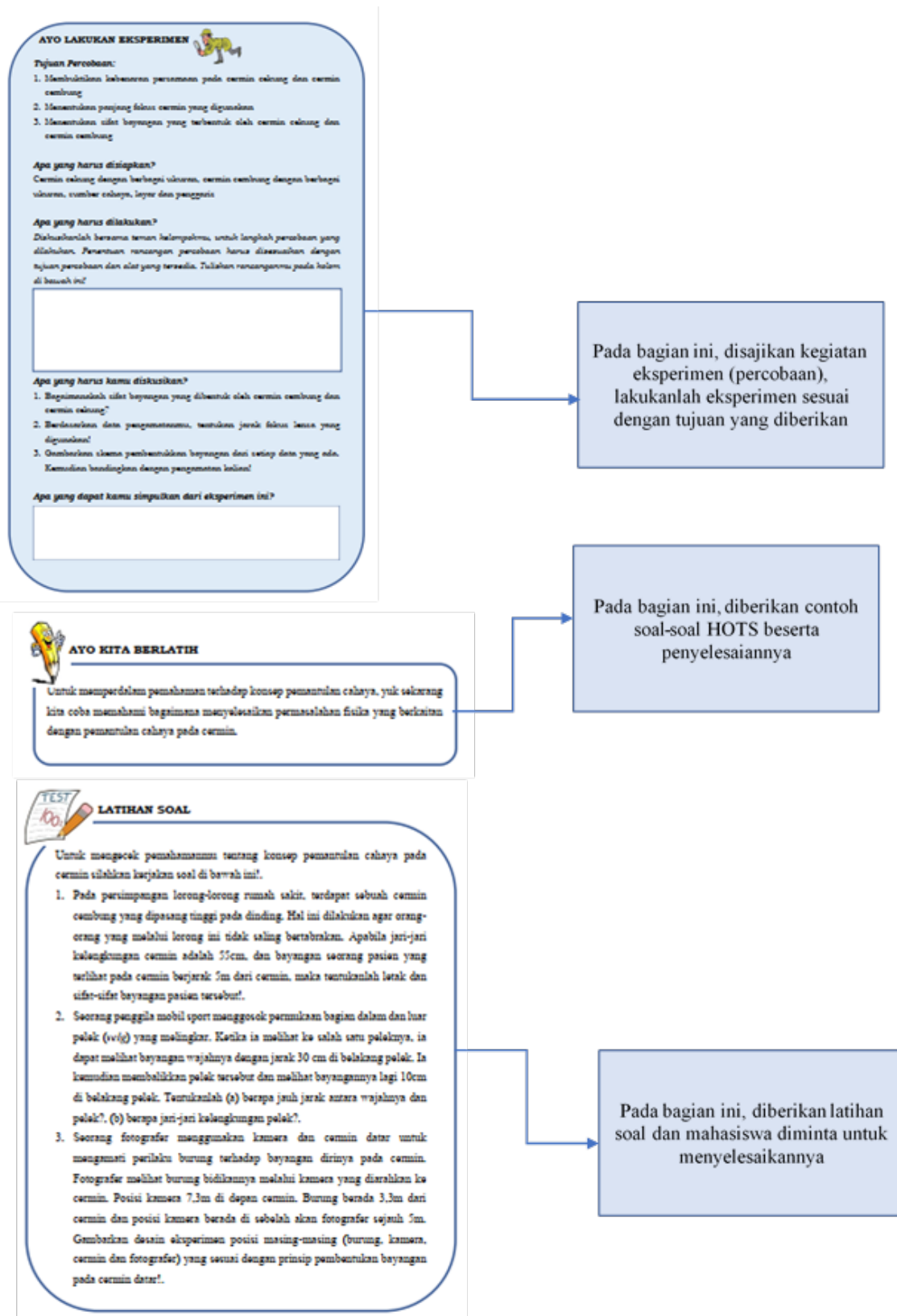


Figure 3b. Activity Steps in a Problem-Solving-Based Module

After the formulation of the problem has been agreed upon, the third step is formulating the hypothesis. Students are asked to formulate hypotheses

or temporary answers and write them in the "Formulating Hypotheses (*Merumuskan Hipotesis*)" column. In this step, students recall previously obtained

information and relate it to the newly obtained information. Students obtain new information by reading the material presented in the material column and are directed to look for other relevant reference sources. Based on the information obtained, students are then asked to do the fourth step, designing an experiment to find answers to prove the hypothesis. The experimental design is written in the "Let's Experiment (*Ayo Berekspemen!*)" column. Students are asked to write down the experimental steps and the data collected from the experimental results. In this step, tools and materials that can be used have been presented, so students are more focused on designing experiments. At the end of the "let's experiment" step, students make conclusions by comparing the hypothesis with the results of the experiments.

In the fifth step, students are given examples of HOTS questions and their solutions. In this step, students are expected to be able to practice solving HOTS questions. Furthermore, in the "Let's Practice (*Ayo Berlatih!*)" step, students are asked to solve the given questions by following the sample steps' completion steps. The overall activity steps in the module are presented in Figure 3a and Figure 3b.

Problem-solving based physics learning module has succeeded in leading students to practice problem-solving skills. Problem-solving ability also affects students' HOTS. The results of the analysis in Table 7 show that there are differences in the HOTS of students who have high and low categories.

**Table 7.** Differences in Student HOTS by Category of Problem-Solving Ability

Category of Problem Solving	HOTS Score	
	Mean Rank	Sum of Ranks
High	8.40	42.00
Low	4.00	24.00

Students with high problem-solving skills will be more likely to be able to think critically and be able to develop creativity in learning. The result is in line with research (Suarsana & Mahayukti, 2013) which also shows that reasoning and problem-solving-oriented modules successfully develop students' critical and creative thinking skills. Critical thinking skills and creative thinking are part of the HOTS and are developed in the Learning Outcomes of higher education students based on the Industrial Revolution 4.0 (Junaidi, 2020). Students with high critical thinking skills tend to provide complete problem-solving in every stage of critical thinking (Munawwarah et al., 2020).

High problem-solving ability will lead students to actively participate in every learning process to solve problems. The problem-solving ability makes students' insight and thinking power develop and become aware of various events in everyday life related to the physics concepts being studied (Daryanti et al., 2019). Science

teacher candidates with good problem-solving skills can propose more reasons, evaluate problems from a multi-dimensional perspective, reach healthier solutions, and consider themselves sufficient to solve and try to solve problems. They are confident and plan through problem construction (Bahtiyar & Can, 2016). Thus, the problem solving -based optics module that has been designed will lead students to have HOTS and problem-solving abilities that support student success in studying optics.

**Conclusion**

Problem-solving-based optics learning modules can effectively increase the HOTS of prospective physics teacher students on optics material. This study found that an increase occurred in all aspects of HOTS, namely analyzing, evaluating, and creating, but not yet optimally, there was a change in the aspect of creating. The result suggests that to increase HOTS in the creative aspect, problem-solving-based learning by project-oriented. Through project-oriented problem-based learning, students will be more creative in finding ideas to produce a product in the problem-solving process. In addition, it was found that there was an effect of problem-solving ability on students' HOTS. Students with good problem-solving skills can also solve HOTS questions well. Therefore, problem-based physics learning can be a learning innovation in developing students' thinking skills.

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