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Improving Problem-Solving Skills With Problem-Based Learning Models in Optical Wave Courses

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ABSTRACT

Objective: Problem-solving skills are one of the skills one has to live in the 21st century. Therefore, this research aims to explain the improvement in problem-solving skills using a problem-based learning model in optical wave courses. This research was carried out on 3rd-semester students majoring in undergraduate program Science Education at the State University of Surabaya in two classes. Method: The research design used the one-group pretest-posttest design with one repetition—data collection techniques using observation and test techniques. Observations were made to review practical aspects and tests for reviewing the effectiveness aspects. **Results:** The observation results indicate that the learning process is classified as practical. The average result of problem-solving skills in class U students is better than in class B. Based on their problem-solving skills, students can solve problems to completion. The knowledge test results are in the moderate range. A paired T-test in each class shows a significant difference between the results before and after learning. The achievement of knowledge and skills shows that the problem-based learning model effectively improves their problem-solving skills in the waves and optics courses. **Novelty:** The novelty of this research is the use of four indicators adapted to optical wave material under learning conditions after the COVID-19 pandemic.

INTRODUCTION

Problem-solving skills need to be possessed by elementary, middle, and high school students to support their thinking patterns. According to Lopez-Jimenez et al. (2021), steps to guide, monitor, and assist students in solving problems can develop their critical thinking skills. Since being at the elementary and secondary school levels, the government has designed lessons to train critical thinking and problem-solving skills. Difficulties in everyday life are unpredictable; therefore, practical and valuable skills are needed in the current era (Muhlisin et al., 2022). The ability to solve problems plays an essential role in the survival of society (Nurjannah et al., 2021). According to Haryani et al. (2021), as has been done by many other countries, in 2017, the Ministry of Education and Culture of the Republic of Indonesia began to promote curriculum integration in learning skills and innovation in the 21st century, known as the 4Cs: creativity and innovation, critical thinking and problem-solving, collaboration, and communication. Critical thinking has become one of the main goals of education in the 21st century because global market trends also require graduates to apply their critical thinking skills to the work environment (Wijayati et al., 2022). Critical thinking skills can be developed by integrating problem-based learning models into learning (Masruro et al., 2021). One of the thinking skills that can be developed is problem-solving skills needed in the 21st century (Batlolona et al., 2018).

Education is an essential factor for humans. Education is supporting the improvement of the quality of human resources (Widarti et al., 2020). The application of 4C skills and innovations that already exist in elementary and secondary schools will have maximum results if it is continued at a high level, even with a different learning package. According to Kaczkó & Ostendorf (2022), university education aims not only to provide education in the professional field but also to cultivate critical judgment and the ability to think critically and conceptually. Therefore, students can be recognized with 21st-century skills and taught to apply social values professionally (Muzana et al., 2021). The 4C skills and innovations of 21st-century learning are applied to prepare Indonesia's young generation to survive and compete in the 21st century. That is, teachers must be innovative in preparing students for the demands of 21st-century skills (Iskandar et al., 2021).

Critical thinking, namely, the ability of students to think critically in the form of reasoning, expressing, analyzing, and solving problems. Underdeveloped critical thinking skills require a learning process where students actively explore their knowledge and can understand concepts and analytical skills properly and correctly to have good critical thinking skills (Alvionita et al., 2020). According to Paul & Elder (2020), critical thinking is the art of analyzing and evaluating thinking processes to improve them. Critical thinking skills and problem-solving are two interrelated abilities. According to Paul & Elder (2020), critical thinking is independent thinking, self-discipline, self-monitoring, and self-correctional thinking. A maximum critical thinking process can be realized with communication between individuals (Palennari et al., 2021). Research is designed to be discussed in groups, and forming collaboration in a working group will lead to problem-solving. A presentation and evaluation are held at the end of the learning discussion. This is intended to review the work that has been done in order to get maximum results. Collaboration between learning components, namely students, teachers, and learning resources, is expected to train critical thinking skills (Sundari et al., 2020).

Problem-solving ability can be easily achieved if armed with critical thinking skills. Problem-solving has one characteristic, reflection, which supports teaching students' thinking skills (Asy'ari et al., 2019). Problem-solving skills are crucial in learning and everyday life (Qotrunnada, 2022). The ability to solve problems originates from and grows from the human cognitive system, which consists of related stages, namely identifying, understanding, solving, and evaluating (Savitri et al., 2021). Problem-based learning engages students actively in independent inquiry and enables them to interpret and explain natural phenomena and construct their understanding. In understanding the problem, routinely read the problem, often intending to think of a solution plan (Mairing, 2020). In the problem-based learning model, students can explore and investigate (Marnita et al., 2020). Finally, this problem-based learning will help students become independent learners (Arends, 2012). The syntax for problem-based learning or problem-based learning (Arends, 2012), namely, phase 1: orient students to problems; phase 2: organize learners to learn; phase 3: assisting independent and group investigations; phase 4: developing and presenting the work; phase 5: analyze and evaluate the problem-solving process. Indicators to measure that students have gone through a problem-solving learning process using indicators from (Mustofa & Rusdiana 2016) with modifications. Problem-solving indicators, namely, visualizing known variables in the problem, writing down the concepts used to solve the problem, using variables in applying the concept, and checking and evaluating solutions.

This research applies problem-based learning to help students improve their problem-solving skills. Selection of the right learning model can help lecturers convey learning material so that students can understand it (Uliyandari et al., 2021). Problem-Based learning is emphasized to train students in the ability to analyze a given problem so that students can practice critical thinking skills. This critical thinking ability is needed in the face of an increasingly varied era of problems that must be faced (Masruro et al., 2021). Problem-based learning is characterized by using authentic problems. Solving problems with science learning that studies natural phenomena is contextual to finding a theory that is considered; problem-solving skills are needed in studying it (Febrianto et al., 2019). Based on research that has been conducted by Dwikoranto (2022) on problem-solving using the Toulmin argumentation pattern as an alternative to learning during the COVID-19 pandemic, which has obtained good results in increasing problem-solving abilities, the novelty of this research is the use of four indicators that have been adapted to optical wave material under conditions of learning after the COVID-19 pandemic.

In the Optical Waves course, the material used is an optical device very close to students. Optical Waves is a course that studies waves first, then flows from studying light waves into a discussion of optics. This research was carried out when entering the material regarding optics. In optics, light is the main factor influencing optical devices' working principle. The light beam was originally thought to consist of particles. However, gradually the phenomena of interference and diffraction were discovered, which could be explained by assuming the wave model of light. The prominent role of light is to help the working principle of the optical device through the entry of light and the formation of shadows on the optical device. Humans use the eye to see, which is a natural optical instrument. The optical tools we use daily pose a real problem in knowing the working principle and the nature of the image produced. In solving physics problems, students apply their knowledge and abilities to achieve certain goals (Setyarini et al., 2021). Learning by using a problem-based learning model aims to make students able to discover how optical devices work and the nature of the shadows that will be formed. This research aims to improve students' problem-solving abilities in optical wave courses, especially in four indicators; there are visualizing the known variables in the problem, writing down the concepts used to solve the problem, using variables in implementing concepts, and checking also evaluating solutions.

RESEARCH METHOD

This research was tested on undergraduate program science education students at Universitas Negeri Surabaya in two classes. Class U, totaling 15 students, and Club B, totaling 22 students. Implementation time in semester 3 of the 2022/2023 school year. This type of research includes pre-experimental research with the research design used, namely a "One-Shot Case Study" (Sugiyono, 2015) with one repeater in **Figure 1**.

$$X \rightarrow O$$

Figure 1. Illustration One-Shot Case Study
Source: Sugiyono, (2015)

X = Treatment that is given
O = Observation

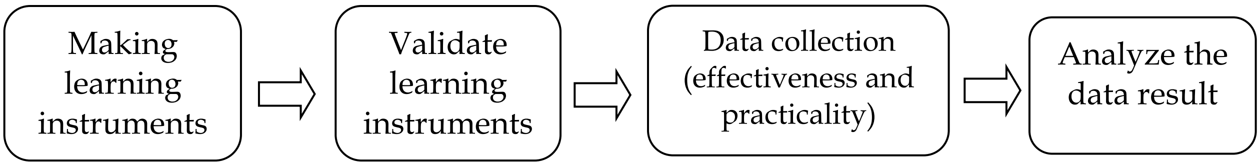

Figure 2. Flowchart of research procedure.

The research procedures carried out, as in **Figure 2**, validating the devices used, a pretest-posttest to measure the increase in learning outcomes after Treatment, worksheets containing problem-solving indicators, and observations for implementing learning. The learning instruments were validated by one lecturer at the State University of Surabaya and two alums of graduate students at the State University of Surabaya. The learning device was validated by three validators and declared 93.0% valid. The details of the validation results are likely in **Table 1**.

Table 1. Validation results.

Aspect	Score Average	Validity Percentage	Validity Statement
Student worksheets	4.6	92.0%	Very valid
Study plan	4.6	92.0%	Very valid
Test question	4.8	96.0%	Very valid
Average	**4.7**	**93.0%**	**Very valid**

The validity results are accompanied by reliability results using the Borich method.

$$R = \left(1 - \frac{A-B}{A+B}\right) \times 100.0\%$$

R = Instrument reliability (data reliable if gets a reliability value ≥ 75.0%)
A = Highest frequency of assessment
B = Lowest frequency of assessment

Analysis of problem-solving skills uses four indicators: visualizing known variables in the problem, writing down the concepts used to solve the problem, using variables in applying the concept and checking and evaluating solutions. The data gets a reliability value of 75.0%, declared reliable—analysis of student test results from pretest and posttest scores. Scores were collected from each student and then analyzed using the N-gain score and paired T-test. The N-gain score is the difference between the posttest scores and pretest scores.

RESULTS AND DISCUSSION

Results

Assessment of the implementation of learning through observation sheets that contain learning activities. Assessment of the implementation of learning was carried out by three observers, namely students of the science education master's program at the Surabaya State University Postgraduate Program. The learning activities listed on the observation sheet start with preliminary, core, and closing activities. Learning activities are detailed according to the flow and syntax of learning. The results of the observations from the three observers showed an average score of 90.0 out of a total score of 100. In addition, during the learning process, students were enthusiastic about participating. This shows that the implementation of the learning that has been done can be practical. Learning activities, of course, refer to the model used, which is a problem-based learning model. The syntax listed in the learning activities refers to Arends's problem-based learning model reference book (2012). The results of the observations of the three observers are shown in Figure 3.

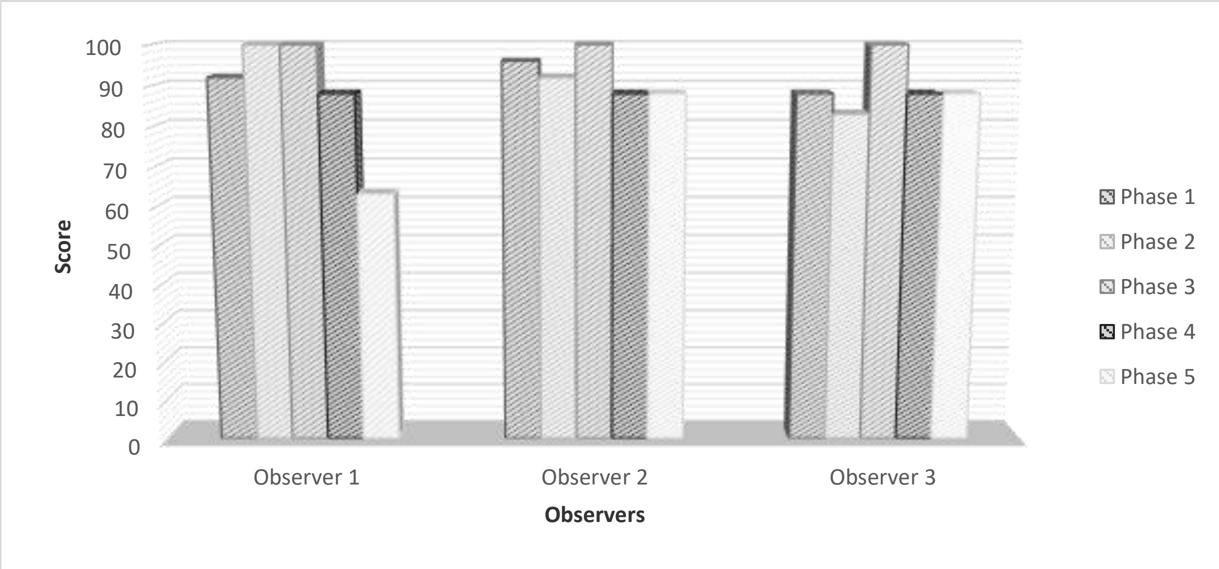

Figure 3. The results of learning observations are based on syntax.

In phase 1, orienting students to the problem, observer 1, observer 2, and Observer 3 gave a score of 92.0, 96.0, and 88.0. Phase 2 organizes students to learn; an observer scores 100.0, 92.0, and 83.0. In Phase 3, helping independent and group investigations, the three observers scored 100.00. In phase 4, developing and presenting work results, all observers gave a value of 88. Finally, in phase 5, analyzing and evaluating the problem-solving process, observers gave it a value of 63.00, 88.00, and 88.00. Phase 1 up to Phase 4 was carried out well, and students were enthusiastic about the learning process. However, in phase 5, one observer scored 63 because when one group presented their work, the other group gave little response in the form of questions or additions to the material presented. The advantages of the PBL model include; Students become accustomed to facing problems and will be challenged to solve new problems and practice a sense of togetherness, intimacy, and cooperation between friends so that they are accustomed to having discussions together in dealing with a problem (Masruro et al., 2021).

Assessment of the effectiveness of learning in terms of the results of student pretest-posttest and problem-solving skills in learning activities contained in Student Worksheets. Data analysis of pretest-posttest values using N-gain and paired T-test. Class U consisted of 15 students, and the N-gain value was 0.4, classified as moderate or medium. In class B, which consisted of 22 students, an N-gain value of 0.45 was also classified as moderate or medium. It is said to be effective if students' learning outcomes obtain an n-gain score > 0.3 with medium or high criteria (Kurniawan & Hidayah, 2020). The moderate category means an increase between the pretest and posttest, but the increase is insignificant. Before conducting the paired T-test, the data were analyzed for normalization, and the results showed that the data met the normalized requirements. The method used to examine the causes of reconciliation is a statistical hypothesis test using the Independent Sample T-Test (Magdalena & Krisanti, 2019). The results of the data analysis using the paired T-test for the two classes showed differences before and after learning was carried out. In class U, the calculated T value is 8.6, and the T table value is 1.7, so the calculated T value is> T table. In class B, the calculated T value is 10.2, and the T table value is 1.7, so the calculated T value is> T table. The results of the two classes are the same, namely the value of T count > T table, so there are differences before and after learning is carried out.

Assessment of problem-solving skills refers to indicators from Mustofa & Rusdiana (2016) that have been modified. Problem-solving indicators consist of visualizing known variables in the problem, writing down the concepts used to solve the problem, using variables in applying the concept, and checking also evaluating solutions. The results of the problem-solving skills test for class U got an average score of 77.6, and for class, B got an average score of 63.2. Students with higher capacities are expected to be able to understand concepts, map problems, and choose the best solutions to the problems they experience (Herawati et al., 2021). In the research results obtained, students achieved good results, so in the future, it will be necessary to improve problem-solving skills to reach a high or perfect level. Critical thinking skills must be continuously trained in the learning process (Suciati et al., 2022). Problem-solving skills are closely related to critical thinking skills, so the two are mutually sustainable. Problem-solving requires integrated thinking skills and a relevant knowledge base (Nurhairani & Anggraini, 2018).

The problem that students solve is to study the working principles of the types of optical instruments that each group gets. Then, examine the flow of light entering until an image is formed, along with the nature of the image on the optical device. Students solve problems by searching, reading, and studying relevant learning resources. The learning resources used come from relevant main books or research journals. Student activities in constructing knowledge as a basis for problem-solving were carried out by students at the reading stage (Muhlisin et al., 2022). Students' proficiency in studying literature to solve existing problems is a good step toward practicing problem-solving skills and critical thinking. Students' critical thinking skills can be improved through contextual learning; problem-based learning or Problem-Based Learning is appropriate learning to improve students' critical thinking skills (Alifteria et al., 2023).

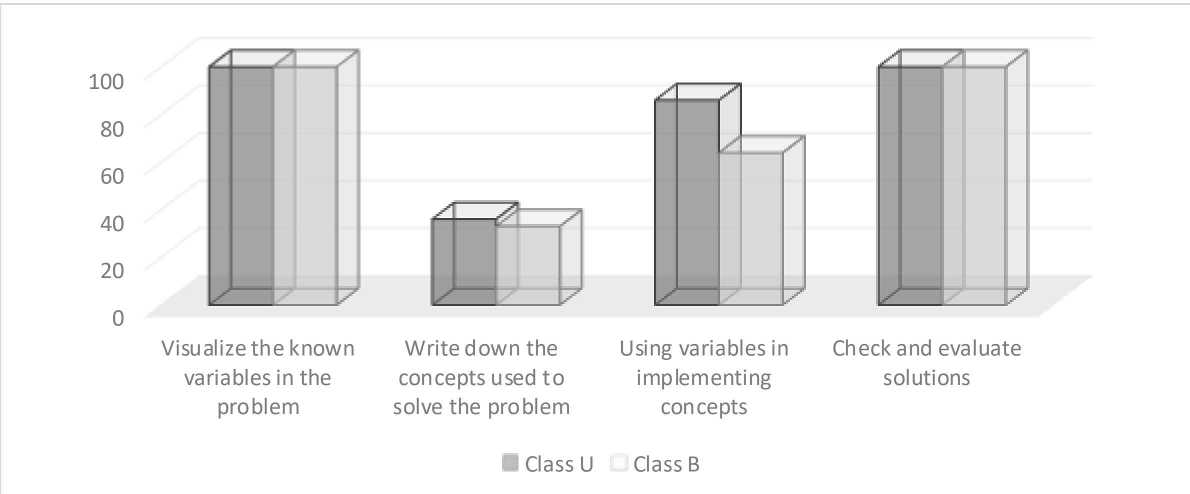

Figure 4. Results of problem-solving skills.

Figure 4 shows the first and fourth problem-solving indicators that show the maximum scores for both classes. The first indicator is that students in both classes can visualize images of light entering the optical device they are studying to form an image. The fourth indicator is that students are able to present the results of their group work well in front of the class. There were few evaluations given by teachers and students from other groups because the concepts they conveyed were right. In collecting Student Worksheets, the majority of the two classes needed to be completed in expressing their answers in writing, even though, at the time, the presentations had been delivered properly. This causes the second and third indicators not to be achieved optimally. A problem must be solved in various ways despite failures, but it takes persistence to find other ways to solve it (Febrianto et al., 2019). That means the imperfection of an indicator cannot be repaired by practicing student perseverance and accuracy. According to Alvionita et al. (2020), PBL learning is supported by constructivism learning theory, where learning is based on the premise that by reflecting on the experience, someone can build an understanding of knowledge.

Discussion

The two instructions the teacher gave, namely, presenting and completing the Student Worksheet, took precedence over the first instruction. Their short-term memory can cause less attention to the second instruction. Short-term memory is a storage system that can store limited information for a few seconds. Thoughts realized at a particular moment are stored in short-term memory; when we stop thinking about something, it disappears from our short-term memory (Slavin, 2006). Another thing that affects the need for better information capture is how to communicate it. Using more communicative language can help students determine actions in work procedures (Kurniawan et al., 2019).

Table 2. Details of the results of problem-solving skills based on indicators.

<table>
<tr><th>Indicator</th><th>Sample</th><th>Results</th></tr>
<tr><td rowspan="2">Visualize the known variables in the problem</td><td>Class U</td><td rowspan="2">From the five groups for each class, all groups could describe the incoming light to form an image on the optical instrument with a description of the name of the light.</td></tr>
<tr><td>Class B</td></tr>
<tr><td rowspan="2">Write down the concepts used to solve the problem</td><td>Class U</td><td>– Two of the five groups could write down the working principles of optical instruments clearly and thoroughly.
– One group wrote down the working principles of optical instruments that must be clarified and completed.
– The other two groups still need to write down the answers.</td></tr>
<tr><td>Class B</td><td>– Three groups wrote about the working principles of optical instruments that needed to be clarified and completed.
– The other two groups still need to write down the answers.</td></tr>
</table>

Indicator	Sample	Results
Using variables in implementing concepts	Class U	– Three groups wrote down the principles of image properties from optical instruments clearly and thoroughly. – The other two groups wrote the principles of image properties from optical instruments that needed clarification and completion.
	Class B	– The other four groups wrote about the principles of the nature of the image from the optical instrument in a more precise and complete manner. – One group should have written down the answers.
Check and evaluate solutions.	Class U	Of the five groups for each class, all groups could present their work results clearly, and entirely and discuss them with other groups.
	Class B	

In the PBL process, all activities arranged are systematic. The flow of problem-solving skills begins when students are divided into groups and the type of optical device for each group (Shofiyah & Wulandari, 2018). In the initial indicator, students are asked to describe the light that enters the optical device until the image is captured. The second indicator is that students are asked to explain the working principle of optical instruments, from incoming light to forming an image. The third indicator is that students are asked to find out the nature of the image formed on the optical device. Students conduct literature studies to solve the problems that have been presented. Students carry out literature studies on several textbooks relevant to optical wave material. Textbooks based on collaborative learning models describe scientific literacy skills and student responses (Afnan et al., 2023). The fourth indicator is that students present their work to be evaluated together.

Based on the details in **Table 2** of the results of problem-solving skills in the second indicator, four groups needed to be more apparent in writing down the working principles of optical devices, and two groups needed to write down answers on the collected student worksheets. In the third indicator, six groups needed to be more apparent in writing down the nature of the image produced by the optical instrument, and one group did not write down the answers on the collected student worksheets. Imperfections in the second indicator are caused by students presenting their work rather than wholly deforming it on the worksheets collected. Imperfections in the third indicator, only two of the characteristics of the image are written, for example, virtual upright, not equipped with enlarged or reduced shadows. Short-term memory factors influence written answers' incompleteness when the order is given, so they forget and only focus on the presentation. Short-term memory is a storage system to temporarily stores information when someone is doing a cognitive task (Julianto, 2017). External factors could also influence the completeness of the collected student worksheets. Learning time is carried out during the day, so students are less enthusiastic and lazy to study (Nirwana et al., 2021). According to research conducted by Sutriani & Mansyur (2021), the low ability of students to solve this problem is triggered by several factors, including 1) weak memory, 2) does not match the indicators of the problem-solving stage, 3) lack of student motivation, 4) anxiety, doubt and carelessness, 5) lack of students' ability to make representations, 6) low ability of students in terms of understanding concepts, 7) the strategies used are not appropriate.

CONCLUSION

Fundamental Finding: The developed learning tools are considered feasible to implement in terms of validity, practicality, and effectiveness. **Implication:** Based on the observer's assessment, the implementation of learning is classified as practical. Effectiveness in terms of the N-gain score, the test results for class U and class B are moderate. The test results reviewed by the two classes' paired T-test showed significant differences before and after learning. The results of the problem-solving skills test for class U and class B are good. Hence, the effectiveness of learning using the problem-based learning model is quite effective in increasing the problem-solving skills of undergraduate students. **Limitation:** The limitation of this research is that it uses a problem-based learning model with four indicators of problem-solving on the material of how optical tools work to form images and the nature of the resulting shadows. **Future Research:** The researcher's suggestion based on the research that has been done is that it is necessary to bring examples of actual optical instruments so that students not only solve problems through studying literature but also directly practice their working principles. In addition, it is necessary to have trigger questions in Student Worksheets so that students think more critically. Further research can expand problem-solving indicators that can be added to find problems yourself and can be applied to other learning materials.

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