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Student Worksheet of Light and Optics for STEM-Based Problem-Based Learning: Critical Thinking Skills Perspective

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Abstract: This study investigates the effectiveness of student worksheets in an integrated Problem-Based Learning model using the STEM approach on light and optical materials towards improving the critical thinking skills of eighth-grade students of SMPN 1 Kepanjen. Student worksheets were developed using the 4D model of Thiagarajan (1974). This study was a pre-experimental design using a one-group pretest-posttest. The research instruments were critical thinking ability tests and questionnaires. The paired sample t-test results showed a significant difference in students' critical thinking skills before and after learning on the STEM-based Problem-Based Learning student worksheet. Supported by an N-Gain score of 48.14%, the developed students' worksheet effectively improves students' critical thinking skills.

Keywords: high level of thinking, media for STEM education, science teaching, innovative worksheet

INTRODUCTION

The world's science and technology are experiencing rapid progress in the fields of education, information, communication, economics, and technology (Redhana, 2019). That progress can have a positive impact on students. These advances help students overcome the challenges of 21st-century learning by recognising their critical and creative thinking, communication, collaboration, and scientific literacy skills (Miyarso, 2019). The transition from the national curriculum to the 2013 curriculum is one of Indonesia's efforts to prepare students for 21st-century learning.

Based on the results of the 2018 Program for International Student Assessment (PISA) survey initiated by the Organization for Economic Co-operation and Development (OECD) in March 2019, Indonesian students were ranked 72nd out of 78 countries, with an average score of 371 in literacy aspect and ranked 70th with an average score of 389 on the science aspect. The score of students in Indonesia is still relatively low compared to the OECD average of 487 in the literacy aspect and 489 in the science aspect (Schleicher, 2019). The literacy aspect shows the ability of students to build knowledge, think critically, and make the right decisions. The science aspect shows the ability of students to identify accurate explanations of known scientific phenomena, use that knowledge in identifying simple cases, and determine whether a conclusion is valid based on the data presented (Schleicher, 2019). PISA results show that students in Indonesia have lower critical thinking skills in both literacy and science aspects compared to countries that participate in PISA. This phenomena lead to a need for boostering students soft skills including creativity (Nafiah et al., 2025), problem solving (Rohmah et al., 2025) and others required skills.

Skills in investigation and problem-solving are still hampered in science learning. Emphasis on memorising concepts without involving students in the process of finding, understanding, and developing concepts is still carried out in science learning (Rahmawati et al., 2020). This causes low critical thinking skills in students. Students' critical thinking skills are considered important in order to clarify their understanding of the subject matter. Besides that, critical thinking skills will help students in social life and careers (Widodo, 2021). Students' critical thinking skills are the ability to solve students' problems through their knowledge and intellectual abilities. Critical thinking ability is the ability to solve problems sensibly according to logical steps, and the results of solving these problems are more efficient (Utami et al., 2017). Interviews with teachers of SMPN 1 Kepanjen show that students' critical thinking skills in science subjects, especially light and optics, are relatively low. This is supported by the large number of students with learning outcomes below the KKM. The method used to learn science is assignments and lectures. The teacher uses the learning model recommended in the 2013 curriculum, discovery learning. However, the model is not implemented optimally.

Students assume that learning science is difficult to understand. They also feel that the learning tools used are boring. The material in the book is conveyed to students without a search and investigation process, so it can only be remembered and memorized in the mind. This makes students feel not actively involved, so there is no interaction between teachers and students in learning. Besides that, learning is only focused on teachers, and students are not trained to think critically when finding and formulating something. Studies regarding the profile of Indonesian students' critical thinking is still unsatisfied (Dewi et al., 2020; Rahmadhani & Novita, 2018).

As stated above, one of the causes of the problem of learning science is the lack of appropriate learning tools. Student Worksheets can be a solution to improving students' critical thinking skills. A student worksheet is a collection of sheets containing the steps taken by students. Student worksheets are a form of teaching materials that complement or support the implementation of the Learning Plan (RPP) (Prastowo, 2014). Student worksheets serve as tools that make it easier for students and teachers during learning (Abdurrahman, 2015). The advantages of using worksheets for learning are that they increase efficiency and motivation, encourage active learning based on experience and are consistent with learner-centred learning (Ibrahim et al., 2017). Student worksheets, widely used by teachers, are still inadequate for building students' critical thinking skills. Besides, student worksheets do not emphasise the practical learning experience, so students are less motivated to learn. Other research Afiyanti et al. (2022) has found that using work-based chemical balance teaching materials and scientific approaches (BA-KK-KPI) can effectively improve student learning outcomes.

In this study, a student worksheet (LKPD) was developed based on Problem Based Learning (PBL) integrated in Science, Technology, Engineering, and Mathematics (STEM) as a means of improving students' critical thinking skills. Problem-Based Learning uses constructivist principles to encourage the application of prior knowledge, collaborative learning, and active engagement. The beginning of PBL activities is that a small group of students analyse problems, identify relevant facts, and apply knowledge and experience to solve problems (Seibert, 2021; Zhou, 2018). According to Arends, PBL steps are: (1) problem orientation; (2) organise students in learning; (3) independent or group investigations; (4) develop and produce works; and (5) analyze and evaluate problem-solving activities (Shofiyah & Wulandari, 2018). Problems in PBL activities must be problems or situations relevant to a particular activity that include missing information or unclear answers such as unstructured case studies (Miner-romanoff et al., 2019).

This PBL-based LKPD will be integrated with the STEM approach. The National Research Council explains aspects of STEM, namely: (1) Science is a unit of knowledge that is accumulated through scientific research processes that can produce new knowledge; (2) Technology consists of all systems of processes, people, knowledge, organizations, and devices that create and operate them; (3) Engineering is a collection of knowledge related to design and creation; (4) Mathematics is a field that examines patterns and relationships in quantities, numbers, and spaces and is used in science, engineering, and technology (Council, 2014).

STEM is an approach that links various fields of science. Science requires mathematics to process data, while technology and techniques are the application of knowledge about science (Afriana et al., 2016). STEM is an effective way of facilitating and maintaining the integration of science, technology, mathematics, and engineering (Estapa & Tank, 2017). In the context of STEM, PBL is very suitable as the main pedagogy for STEM learning (Odell et al., 2019). Efforts to improve students' soft skills is a need for science teaching in this era. In their review, Nafiah et al. (2025) suggested to emply project-based learning (PjBL) for improving students' creativity.

The results of the study prove that STEM-based teaching materials have an effective impact on student learning outcomes both in terms of knowledge, skills or attitudes (Izzah et al., 2021). In another study, PBL-based worksheets that are integrated with green chemistry and ethnoscience are useful for increasing students' thinking skills in three thinking domains, namely cognitive, psychomotor, and affective (Sudarmin et al., 2019). Besides that, in other studies regarding the application of the PBL model combined with STEM-based LKPD related to environmental pollution materials, it can improve students' critical thinking skills (Hasanah et al., 2021). Therefore, in order to improve students' critical thinking skills on light materials and optical instruments, it is necessary to develop a student worksheet with an integrated PBL model with a STEM approach.

METHOD

This type of research is a pre-experimental design and uses a one-group pretest-posttest. This design is designed to examine the impact on students' critical thinking skills when using STEM-integrated PBL-based worksheets. The research was conducted at SMPN 1 Kepanjen Malang Regency involving 30 students of class VIII F as the experimental class. The first step of this research is preparation by preparing research instruments in the form of teaching materials, evaluation questions, and lesson plans. The RPP used is based on light materials and optical instruments. 30 multiple choice questions were used as evaluation questions. Prior to the study, an analysis was conducted on evaluation questions with empirical validation. Based on empirical validation with SPSS 25, 16 valid questions were obtained, and Cronbach's Alpha value was 0.831 > 0.60, so the questions were declared reliable. Only 16 valid questions were used as instruments for data collection.

The teaching materials used are LKPD based on the STEM integrated PBL model. LKPD is prepared using a 4-D (four D) development model. Thiagarajan et al. (1974) with a pre-experimental design. The 4-D development model consists of 4 main steps are Define, Design, Develop, and Disseminate.(Thiagarajan et al., 1974). The steps performed are based on the 4D model of Thiagarajan et al. (1974) as follows: (1) define, in this step a preliminary study is carried out by means of a literature study and needs analysis; (2) design, in this step the researcher develops the initial product in the form of LKPD and test instruments that are in accordance with the material; (3) develop, in this step validation and readability tests are carried out; (4) disseminate, in this step the LKPD is distributed and the effectiveness is carried out using a one-group pretest-posttest design as a measurement of critical thinking skills. The last step of this research is processing and analyzing research data to prove the research hypothesis.

The research instruments are tests and questionnaires. All instruments go through an analysis process first by testing the validity and reliability. The data acquisition technique used is a test technique. The test technique consists of pretest-posttest questions to measure critical thinking skills and a questionnaire to measure the readability of the developed teaching materials. The analysis used in this research is descriptive analysis and inference. Inference analysis was carried out using normality and homogeneity tests. To test the effectiveness of learning using STEM-based PBL-based worksheets on students' critical thinking, a t-test was conducted with a paired sample t-test and a significance level of 0.05.

RESULTS AND DISCUSSION

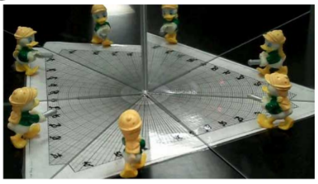
The STEM-based PBL-based LKPD is used for light and optical materials. Student worksheets consists of student worksheets for students and for teachers. The students' worksheets are equipped with a problem orientation in the form of an orientation article or video, a list of learning resources, experiments, and evaluations. One of the advantages of this worksheets is that it contains PBL syntax equipped with STEM aspects at each step that students take during learning. Besides that, simple experiments can be carried out either in the classroom or at home. This supports students to explore their knowledge through problem orientation and integrate it with the findings of the experiment. In the student worksheets, the teacher's handbook is equipped with an answer key for each syntax and assessment guide.

The front page shows the material's title, the author's name, and the model and approach used. An example of the contents of the student worksheets is shown in Figure 1.

Percobaan 3

Alat/bahan	Jumlah
Cermin datar kecil	2 buah
Plester perekat	1 buah
Busur derajat	1 buah
Penjepit kertas atau benda kecil lain	1 buah

Langkah Percobaan



Gambar 3 susunan alat dan bahan pada cermin bersudut
(Sumber: fisikabc.com)

1. Susunlah alat dan bahan seperti gambar di atas!
2. Aturlah sudut yang dibentuk kedua cermin sebesar 120^0!
3. Letakkan penjepit kertas di antara kedua cermin seperti pada gambar!
4. Hitunglah berapa jumlah bayangan yang terbentuk pada gambar! Mengapa bayangan yang terbentuk lebih dari satu?
5. Jika sudut antar cermin diubah menjadi 90^0, berapakah jumlah bayangan yang terbentuk? Apakah hubungan dari sudut kedua cermin? Jika sudut yang dibentuk lebih kecil, maka jumlah bayangan yang terbentuk lebih sedikit atau lebih banyak?

Figure 1. An example of the contents of the student worksheets

Figure 1 is the content of the STEM-integrated PBL-based student worksheets used in this study. Not only the questions that are displayed, but students worksheets also displays initial questions that are in accordance with problem orientation and experimental instructions equipped with lighter questions that encourage students to think critically and provide more real experience in finding concepts in the material through investigation. The student worksheets validation data that supports this research are presented in table 1. Besides that, the table of the results of the teacher and student readability questionnaires is presented in table 1. The two data then become a reference for the feasibility of the student worksheets to be used in learning.

Table 1. STEM-integrated PBL-based student worksheets validation

Rated aspect	Percentage	Criteria
Material Validation		
- Suitability - PBL model - STEM approach - Concept truth - Language standard	91,36%	very suitable
Media Validation		
- Design and layout - Hyperlink	92,86%	very suitable
Mean	92,11%	very suitable

Table 1 is the result of the worksheet validation by the validator, the instructor. The validation aspect is in the form of material and media validation using a questionnaire. Suitability is assessed by KD, GPA and learning objectives. The PBL model is presented with the syntax in the student worksheets. There are also applications of each aspect of the STEM approach. Designs and layouts are judged on the selection of colors, text, and the proportions of each design element. The student worksheet is equipped with a hyperlink to the list of reading sources and a QR code for problem orientation.

Table 2. STEM-integrated PBL-based LKPD readability questionnaire

Rated aspect	Percentage	Criteria
Legibility by teacher		
- Readability and display - Learning and materials	76,21%	suitable
Legibility by students		
Readability	83,81%	very suitable
Mean	80,01%	very suitable

The steps in the LKPD are adapted to the PBL model which has the following syntax: (1) problem orientation; (2) organizing in learning; (3) self-investigation; (4) presenting the work; and (5) evaluation (Shofiyah & Wulandari, 2018). At the stage of problem orientation and organization for learning to get a value of 4 out of a maximum value of 5. This can be due to the problems posed according to real life, but it would be better if the problems were obtained by the students directly. Organizing for learning in the form of an invitation to literacy in several trusted sources. It will be better if organizing can be an opportunity for students to discuss in groups so that they can develop their critical thinking skills. Grouping is a feature of cooperative learning (Wulandari et al., 2017).

Based on the feasibility test, the PBL-STEM-based LKPD meets the printing feasibility standard. The assessment standard by the National Education Standardization Agency (BSNP) states that the feasibility standard of printed materials can be assessed from the aspect of content, presentation, and language (BSNP, 2014). Aspects of the presentation of learning is considered very feasible. This proves that the content of the learning media is systematically arranged with the right order of presentation.

The results of the readability questionnaire showed that the developed student worksheet was easy to understand in its use for students to think critically. According to the teacher, the worksheet can promote students' critical thinking skills in terms of critical thinking supported by the student worksheet. The teacher thinks that the aspects of the student worksheet are in accordance with the PBL model and the STEM approach. Students appreciate that the student worksheet is easy to use with language that is easy to understand. In addition, the student worksheet makes it easier for students to learn independently. This is in accordance with the advantages of using student worksheet for learning, increasing efficiency and motivation, promoting active learning based on experience, and being consistent with learner-centered learning. (Ibrahim et al., 2017). Based on the results of the questionnaire, the student worksheet developed is very suitable for use in learning.

Validation and reliability tests were conducted on pretest-posttest questions to measure students' critical thinking skills. The results of the expert validation of the instrument are shown in Table 3. In addition, the bivariate Pearson correlation test was conducted to test the validation of the test questions.

Table 3. The expert validation of the test questions

Rated aspect	Percentage	Criteria
Content suitability	99,33%	very suitable
Language standard	92,67%	very suitable
Mean	96%	very suitable

Table 3 is the result of a validation test of the questionnaire by experts. The validation aspect is the appropriateness of the content and language used. Conformity is seen from the GPA, question indicators, Bloom taxonomy, and critical thinking indicators on test questions. Sentences in questions use language that is easy for students to understand and free of ambiguity. After expert validation, an empirical test is conducted on the questions. The sample from the empirical test was 50 students of class IX SMPN 1 Kepanjen who were randomly selected. The results of the empirical test are the results of bivariate Pearson correlation and Cronbach's alpha.

Based on the results of the Pearson bivariate correlation, out of the 30 questions developed, it is known that 19 questions are valid and 11 questions are invalid. Valid questions are based on the results of $r_{count} > r_{table}$ (0.279). Invalid questions are based on the results of $r_{count} < r_{table}$ (0.279). From these results, 19 valid questions were tested for Cronbach's alpha reliability. The reliability test results of 19 valid questions have an alpha value of 0.831. This means that the developed questions are in the high reliability category and can be used as research instruments. The study was conducted in class VIII F of SMPN 1 Kepanjen to investigate the effectiveness of using LKPD through the pretest and posttest results. The results of the pretest and posttest of the use of STEM-based PBL-based worksheets on light and optical materials are shown in Table 4.

Table 4. Pretest and posttest of the use of STEM-PBL based worksheets

Test Type	Total Students	Mean	Standard Deviation	Minimum Value	Maximum Value
Pretest	30	56,48	12,44	37,50	93,75
Posttest	30	75,83	14,47	43,75	100,00

Table 4 shows that the average of the pretest and posttest increased. To prove that there was a significant difference after using the developed LKPD, a t-test was performed. Before the T-test, the pre-test and post-test data were subjected to normality and homogeneity tests. The results of the normality test of the pretest-posttest mean using the Shapiro-Wilk test and the homogeneity test using the Lavene test. The Shapiro Wilk normality test stated that the data were normally distributed with a significance value > 0.05. The results of the homogeneity test stated that the pretest and posttest values were homogeneous with a significance level > 0.05. This indicates that the value is normally distributed and homogeneous, allowing the t-test to continue.

The results of the paired sample t-test showed a significance level of <0.05 and $t_{count} > t_{table}$. This proves that H_0 is rejected and H_1 is accepted, this means that the use of STEM PBL-based worksheets shows that there is a significant difference in students' critical thinking skills before and after learning. It is proven that the problem-based learning model with STEM-integrated PBL-based LKPD can improve critical thinking skills. The descriptive results obtained also support this. The pretest scores have an average of 56.48 while the posttest scores have an average of 75.83.

Table 5. N-Gain Score Results

Number of samples (*N*)	N-Gain Score (%)		
	Mean	Minimum	Maximum
30	48,14	0,00	100

Table 5 shows the results of the N-gain score, which is used to determine the increase in pretest-posttest scores after learning. The average increase is 48.14% and the results are included in the sufficient criteria. Learning with PBL-based LKPD integrated STEM has been designed to have a positive impact on increasing critical thinking skills of students in grade VIII of SMPN 1 Kepanjen. Students' critical thinking skills are enhanced through the use of LKPD, which facilitates the learning process, explains the relationship of STEM to life, and can be used independently. This is consistent with previous research that the use of LKPD in science learning is effective in helping the learning process, mastering the material, and developing independent study habits for students (Gomba, 2019). It is also supported by other studies that PBL-based worksheets integrated with green chemistry and ethnoscience are useful for improving students' thinking skills in three thinking domains, namely cognitive, psychomotor, and affective (Sudarmin et al., 2019). In addition, in another study of the implementation of the PBL model combined with STEM-based worksheets on environmental pollution material, it was able to improve students' critical thinking skills (Hasanah et al., 2021).

Table 6. The results of the N-Gain Score on each critical thinking indicator

Critical thinking indicator	N-Gain Score (%)
Basic clarification	60
Bases for a decision	61,11
Inference	46,67
Advanced clarification	44,45
Suppotition and integration	50,56

The application of learning with STEM-based PBL worksheets, the teacher accompanies students in analyzing a problem and is connected to the results of the investigation through a simple experiment. Therefore, each student tries his best in the investigation to find links to problems and simple solutions that can be done. In the process, students find more information to analyze an event and result. This can be explained in the following 5 stages of STEM-integrated problem-based learning.

In the first stage of problem orientation, the teacher provides an overview of the learning objectives. In problem orientation, students are confronted with a problem in everyday life. This orientation can motivate students to engage in problem solving activities. One of the critical thinking skills according to Ennis (2011), basic clarification, is developed at this stage. In Table 6, the basic clarification indicator experienced an n-gain of 60% after learning with the PBL-STEM student worksheets. Basic clarification consists of activities that focus, analyze, and answer questions about a statement or explanation of the problem in problem orientation (Ennis, 2011). Problem-oriented questions encourage students to think more critically and to make connections between everyday problems and the material being studied. Questions are also used to stimulate interaction between students and teachers to encourage critical thinking.

In the second stage of organizing for learning, various relevant reading sources are presented to help students connect problem solving to the material. Students are guided in the bases for a decision. In Table 6, the indicator of bases for a decision experienced an n-gain of 61.11% after learning using the PBL-STEM worksheets. Bases for a decision consists of thinking about reliable or unreliable sources on the organization for learning (Ennis, 2011). Students determine and manage what will be done in relation to the problem orientation.

In the third stage of independent inquiry, students are trained to conduct simple experiments. Experiments help students explore concepts in the material. Critical thinking questions complement the experiments. Questions are an important part of learning (Duron et al., 2006). Students' reasoning skills are trained in this phase. In Table 7, the inference indicator experienced an n-gain of 46.67% after learning with PBL-STEM worksheets. Inference consists of considering deductive activities or the results of deductions, generating or considering induction results, generating and determining the value of reasoning in independent investigations (Ennis, 2011).

In the fourth stage, students present their work in the form of a simple report. In this stage, students' advanced clarification skills according to Ennis (2011) are developed. In Table 6, the advanced clarification indicator experienced an n-gain of 44.45% after learning using the PBL-STEM worksheets. Advanced clarification consists of identifying terms, establishing considerations, and reviewing assumptions when presenting work in the form of a report (Ennis, 2011). The purpose of this report is to train students in conveying what understanding has been obtained.

In the fifth stage of assessment, students reflect on their learning by working on assessment questions. The questions are provided with STEM aspects related to the material. The aim is for students to relate the material to everyday life and to analyze STEM aspects of life. Critical thinking indicators according to Ennis (2011) supposition and integration skills are developed at this stage. In Table 6, the supposition and integration indicator experienced an n-gain of 50.56% after learning using the PBL STEM worksheets. Supposition and integration consists of considering the reasons for an answer and integrating the disposition at the evaluation stage (Ennis, 2011).

Improved test scores in the experimental class prove that students respond well when teachers use STEM-integrated PBL-based worksheets on light and optical materials. Treatment with the worksheets developed and validated in the experimental classroom encourages students to think critically at each stage of the problem-based learning model associated with a simple life problem. In addition, the STEM aspect of the worksheets makes students integrate all aspects of STEM in the life of light and optical materials. PBL STEM worksheets can improve students' critical thinking skills. The results of this study are consistent with previous research that the PBL learning model combined with STEM-based LKPD can improve students' critical thinking skills (Hasanah et al., 2021).

CONCLUSIONS

The results of this study prove that STEM-based Problem Based Learning worksheets are very feasible to implement in learning based on expert validation questionnaires and readability questionnaires. The descriptive data from the pretest and posttest results after the implementation of STEM-based Problem Based Learning worksheets showed an increase in the average critical thinking from 56.48 to 75.85. Based on the results of the t-test, it shows that there are significant differences in students' critical thinking skills before and after learning with STEM-integrated PBL-based worksheets. This is supported by an N-gain of 48.14% including the sufficient category, so the developed worksheet is quite effective in improving students' critical thinking skills.

Based on the research results, suggestions that can be considered are (1) STEM-based PBL-based worksheet can be used as an effort to improve students' critical thinking skills, (2) worksheet development can be done better by paying attention to more detailed things in exploratory thinking critical, (3) the need for a control class on the effectiveness test of the LKPD, which was developed as a comparison for the experimental class, (4) the need for a questionnaire to explain the effect of the worksheet on students' critical thinking skills after learning.

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