The influence of PBL-STEM on students’ problem-solving skills in the topic of optical instruments

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Abstract. The research aimed to reveal the influence of Problem Based Learning-Science Technology Engineering Mathematics (PBL-STEM) on students’ problem-solving skills in the topic of the optical instruments. This research was quasi-experimental research using Pre- and Posttest Design. The research subject was 114 grade X students of MAN Tulungagung Indonesia. The classes used in the research, which were called Experiment 1, Experiment 2 and a control class received, respectively, PBL-STEM, PBL, and conventional learning models. The research instrument was students’ Optical Instrument Problem-Solving Skills Test with 0.99 alpha Cronbach reliability. The data were analyzed using one-way ANOVA with post hoc test, N-gain and effect size. The result showed that the learning model influenced students’ problem-solving skills. Experiment 1 acquired significantly higher problem-solving skills than other classes, and Experiment 2 acquired significantly higher problem-solving skills than the control class. Both Experiment classes obtained an increase in problem-solving skills at a level higher than the control class. The practical implementation of PBL-STEM model had a medium impact than PBL class. Furthermore, PBL-STEM and PBL had a huge impact compared with the conventional class in increasing the students’ problem-solving skills.

1. Introduction

Optical instruments are tools such as camera lenses, magnifiers, the human eye, microscopes, and telescopes, which are considered common in our everyday life [1-2]. Understanding the concept of optical instruments requires the knowledge of the ray model of light and the laws of reflection and refraction [1,3]. However, tracing the light ray can be interpreted as an abstract concept by students to cause a misconception. For example, students conceive the idea that the image in the mirror is real [4]. Teachers also make this worse by using abstract explanation in class [5-7] so that students develop a sense that physics is a difficult subject to study [6]. This phenomenon causes a low level of understanding of physics concept among students which affects their ability to solve physics problems.

Problem-solving is a complex cognitive process and an important component in physics learning [8], and also one of the focus in 21\textsuperscript{st}-century learning [9-10]. In order to solve daily problems in an optical instrument, students need this ability as well. However, students’ problem-solving ability is known to be lacking in general. Students commonly treat physics problems like mathematics problems which rely heavily on the use of rigid equations [11]. When faced with a physics problem, students have the tendency to directly apply certain equation or formula without thinking to understand the true nature of the problem [12]. This is caused by the lack of attention the teachers give in regards to the practical
application in day-to-day problems [13] or the lack of training in students’ problem-solving abilities [14-16].

Today’s learning trend focuses on building and developing problem-solving skills as one of the skills in the 21st century [17]. STEM is one of successful approach to improve the skills in 21st century [17-19] in physics learning [20-22]. STEAM approach has been proved to increase the quality of learning process [23-24], which focuses on solving real problems in daily life where students work on ill-defined tasks to become a well-defined outcome through teamwork [25], with meaningful learning context [26]. STEM integrates science, technology, engineering, and mathematics together [27-28] into whole learning to develop students’ knowledge and skill in a friendly manner [29-31]. STEM enable the students to be a better problem solver, innovator, inventor, independent learner, logical thinker, and technological literate [32]. STEAM application in learning can help students to design, develop, and use technology properly; improve cognitive, manipulative, and affective skills; and apply their knowledge [33].

Problem-based learning is one of the learning methods to use real-life problems. The method centered on the student which begins by defining the real-world problem and then solve it [34]. In problem-based learning (PBL), students learn with experience to solve problems derived from real-world occurrences [35]. PBL develops active learning, problem-solving skills and field knowledge [36]. The problems in PBL are related to Science, Technology, Engineering, and Mathematics (STEM). The integration of STEM in learning could be implemented through designed engineering activities [37]. The use of PBL with STEM is expected to improve students’ problem-solving skill.

The integrated PBL with STEM approach can improve students’ problem-solving skills. This study is going to investigate the change in students’ problem-solving skills by comparing the scores in the experiment and control classes after PBL-STEM learning and analyze how it affects the learning process towards students’ problem-solving skills.

2. Method

2.1. Research Design and Participant

This study used quasi-experimental research with Pre- and Posttest Design [38]. The participants of this study were 114 students who studied the optical instrument in three of the classes in Madrasah Aliyah Negeri Tulungagung, Jawa Timur, Indonesia. The three classes used in the research were called Experiment 1, Experiment 2, and Control class. Each of the class had 38 students. The Experiment 1 class was implemented by Science Technology Engineering Mathematics (STEM) education and Problem Based Learning (PBL). The integrated STEM aims to erase the border among disciplines to solve problems in real life. Moreover, PBL, which focuses on students, is a learning model which uses authentic problem in real life in order to improve the students’ problem-solving ability [39-40]. The combination of STEM education and PBL becomes PBL-STEM learning. The PBL had five steps in this learning [41]. The first step is the orientation of the problem. In the second step, teacher organizes students to study. In the next step, the students conduct an experiment to investigate the problem. In these steps, the three aspects of STEM such as science, technology, and mathematics were applied. In the fourth step, students develop and present a product. For this step, all of the STEM aspects were applied. However, the engineering aspect is the most prominent amongst others. The Engineering itself has 7 steps, which are (1) Identify the Problem, Need or Preference, (2) Information Gathering to Develop Possible Solutions, (3) Selection of the Best Possible Solution, (4) Design and Making, (5) Testing to See if it Works, (6) Modifications & Improvement, and (7) Assessment [42]. The last step is to analyze and evaluate the problem-solving process, which involves three aspects of STEM such as steps number 1, 2 and 3 in PBL learning. The Experiment 2 class only implemented PBL without STEM learning. The control class receives traditional learning, which is comprised of conventional methods with general activities, such as examining daily phenomenon, listening to an oral explanation by teachers about the concept and its practical application, and solve written exercises and present the findings in front of the class.
2.2. Data Sources and Analysis
The data were collected through pre-test and post-test. The research instrument was students’ Optical Instrument Problem-Solving Skills Test which consisted of 11 essay questions with 0.99 alpha Cronbach reliability. This instrument was developed based on problem-solving skills indicator especially for optical instruments. The collected data was analyzed using one-way ANOVA with post hoc test, N-gain and effect size. One way ANOVA with post hoc test was used to know the influence of the variance of learning models on students’ problem-solving skills [43]. The analysis used N-gain in order to know the improvement of students’ score [44]. Cohen’s d-effect size was used in order to know the impact of the variance of learning models towards students’ problem-solving skills. Effect size is defined as the strength of the relationship between the dependent variable and the independent variable [43].

3. Result and Discussion
The mean and standard deviation of the pre-test score to measure problem-solving skills in each class is presented in Table 1.

| Table 1. Pre-test score analysis in experiment 1, experiment 2, and control class |
|---------------------------------------------------------------|
| Parameter | Experiment 1 (n=38) | Experiment 2 (n=38) | Control (n=38) |
|-----------|---------------------|---------------------|----------------|
| Mean      | 29.76               | 31.47               | 31.66          |
| Standard Deviation | 10.14             | 7.56               | 8.01           |

From Table 1, it’s evident that all classes have a rather similar score in problem-solving skill which can be seen by the mean and standard deviation result. This indicates that three classes began with the same initial condition of students’ problem-solving skills.

One-way ANOVA test was conducted to measure the similarity in the initial problem-solving skills in three classes. The result is presented in Table 2.

| Table 2. One-way ANOVA test to measure similarity in initial problem-solving skills |
|---------------------------------------------------------------|
| Source | Statistic Test | Sig. | Alpha | Conclusion |
|--------|----------------|------|-------|------------|
| Between group | One way ANOVA | 0.575 | 0.05 | No differences |

Table 2 indicates that there are no differences between Experiment 1, Experiment 2, and Control class in regards to initial problem-solving skills of their students. This is important in quasi-experiment setting, where different treatments are applied to a relatively similar environment. In this case, the change or improvement of students’ problem-solving skill by the end of the experiment can solely be attributed to the differing treatments amongst three classes.

The mean and standard deviation of the pre-test score to measure problem-solving skills in each class is presented in Table 3.

| Table 3. Post-test score analysis in experiment 1, experiment 2, and control class |
|---------------------------------------------------------------|
| Parameter | Experiment 1 (n=38) | Experiment 2 (n=38) | Control (n=38) |
|-----------|---------------------|---------------------|----------------|
| Mean      | 60.20               | 54.96               | 44.89          |
| Standard Deviation | 10.46             | 7.24               | 7.02           |

Table 3 shows that Experiment 1 class has higher problem-solving skills than Experiment 2, and Control class. This proves that the students who learned using PBL-STEM method developed better problem-solving ability than those who learned with PBL without STEM or with conventional learning approach. Table 3 also shows that Experiment 2 has higher problem-solving skills than Control class. This proves
that the students who learned with PBL developed better problem-solving ability than those who learned with conventional learning approach.

One-way ANOVA test was conducted to measure the similarity in the post-experimental problem-solving skills in three classes. The result is presented in Table 4.

Table 4. One-way ANOVA test to measure similarity in post-experimental problem-solving skills

| Source               | Statistic Test | Sig.  | Alpha | Conclusion |
|----------------------|----------------|-------|-------|------------|
| Between-group        | One way ANOVA  | 0.000 | 0.05  | Differences|

Table 4 shows that there’s a difference amongst the three classes in regards to the problem-solving skills of the students. This difference can be attributed to the differing treatments in each class regarding the learning methods, specifically PBL-STEM in Experiment 1 class, PBL in Experiment 2 class, and conventional approach in Control class. These methods each cause significant change in students’ problem-solving skills in their respective classes.

Post hoc Tukey test was conducted to measure the differences of students’ problem-solving skills in each class. The result can be seen in Table 5.

Table 5. Post hoc Tukey test result from post-test data

| Between classes                | Statistic Test | Sig.  | Alpha | Conclusion |
|--------------------------------|----------------|-------|-------|------------|
| PBL-STEM and PBL               | Post hoc Tukey | 0.021 | 0.05  | Differences|
| PBL-STEM and Conventional      | Post hoc Tukey | 0.000 | 0.05  | Differences|
| PBL and Conventional           | Post hoc Tukey | 0.000 | 0.05  | Differences|

Table 5 shows that there are significant differences in students problem-solving skills in each paired class. The average score of the problem-solving skills in PBL-STEM class (60.20) is higher than PBL class (54.96). This shows that PBL-STEM learning in Experiment 1 class has significantly improved students’ problem-solving skills better than PBL learning in Experiment 2 class. The average score of the problem-solving skills in PBL-STEM class (60.20) is higher than conventional class (44.89). This shows that PBL-STEM learning in Experiment 1 class has significantly improved students’ problem-solving skills better than conventional learning in Control class. The average score of the problem-solving skills in PBL class (54.96) is higher than conventional class (44.89). This shows that PBL learning in Experiment 2 class has significantly improved students’ problem-solving skills better than conventional learning in Control class. Therefore, it can be concluded that PBL-STEM approach can increase students’ problem-solving skills better than the PBL approach and that the PBL approach can increase students’ problem-solving skills better than the conventional approach.

PBL-STEM approach is better than PBL and conventional approach to engage the students in active learning and to motivate them. PBL-STEM can be helpful to encourage the students to actively implement the engineering and science aspect, and to acquire deep science and mathematics knowledge to increase students skills and experience to apply their knowledge in daily life [45]. The process involved in product design enable the students to put together and communicate their understanding of the concepts through STEM [46]. Therefore, the concepts which were taught separately can then be realized in real life as a relevant experience. This can motivate students to learn more [47]. Furthermore, by integrating STEM in learning approach, students can also be motivated in their aspiration and future career, and in their interest in mathematics and science [32]. Overall, the increased motivation in PBL-STEM learning can improve students contextual problem-solving skills in daily life [48].

PBL learning is better than the conventional method in regards to the emphasis of students’ problem-solving aspect. Conventional learning has a bigger emphasis on quantitative problem-solving aspect such as mathematical procedure, whereas PBL learning puts more importance in qualitative problem-solving aspect such as analysis in choosing the right concepts and principles which are needed to solve a certain problem [8,49]. This causes the post-test score of PBL class to be better than the conventional class, which means that
the PBL class has a better conceptual understanding of the topic. Conceptual understanding is often associated with students’ problem-solving ability. Students with good understanding and competence of physics concept have a better chance to solve problems they’re facing [50]. For this reason, in PBL learning, students are expected to be able to analyze problems, devise plans to solve problems, implement said plans, and reflect on the result through learning which orientated in conceptual problem-solving ability [50]. It’s clear that PBL is centered on students, where they can collaboratively answer questions and solve problems and then reflect on their experience [51].

An N-gain analysis was performed in the pre-test and post-test data. The result of the analysis regarding the students’ problem-solving skills can be seen in Table 6.

| Table 6. N-gain result in experiment 1, experiment 2, and control class |
|-----------------|-----------------|-----------------|
| Parameter       | Experiment 1 (n=38) | Experiment 2 (n=38) | Control (n=38) |
| N-gain Category | Medium           | Medium           | Low            |
| N-gain          | 0.43             | 0.34             | 0.19           |

Table 6 shows that Experiment 1 class has higher N-gain than Experiment 2 and Control class and that Experiment 2 has higher N-gain than Control class. This indicates that PBL-STEM learning is better than PBL and conventional learning and that PBL is better than conventional learning to improve students’ problem-solving skills. This order of classes is consistent with previous findings in ANOVA and post hoc Tukey which resulted in the same verdict. Both Experiment classes has N-gain score in medium category, which is a level higher than Control class in the low category. The N-gain in Experiment 1 almost reached the threshold of the N-gain average which can be obtained in learning involving active students at the score of 0.48 [52].

Students in PBL-STEM class constructed a science product used to solve a problem specified in the students’ worksheet. Internet access was allowed during class with teacher’s supervision. Students gathered opinions from others and analyzed them to select which can be applied to the project. Each group presented their product in front of the class while other group gave feedbacks and offered improvements if needed. In the worksheet, students can elaborate on how the product can solve the specified problem and estimate the price of the product in the market. This differs with PBL class where students were only asked to design science product. When a group was presenting their design in front of the class, other groups were only allowed to give feedback, comments, or criticism. In the worksheet, there’s only instruction to elaborate on the solution of the specified problem. This differing treatment in two classes caused different activities which resulted in the different increase in students’ problem-solving skills in both classes. It’s evident that STEM education can improve students’ experience through the principal application and general practice [53]. The students in PBL-STEM class were able to improve their ability in the steps of problem-solving skill, which are physics approach, specific application of physics, mathematical procedure, and logical progression [48] with better category than during pre-test. Therefore, PBL-STEM learning is proved to be effective to improve students’ problem-solving skills [54-55].

Students in Control class were only taught the concept through verbal explanation and were asked to do written exercises and present the result in front of the class. This difference in treatment compared to the PBL class caused the difference of activities in both classes and resulted in the different level of improvement in the end. It’s evident that PBL learning can improve students’ problem-solving skills better than conventional learning [56-58].

PBL-STEM class almost reached the threshold of N-gain average that can be achieved in learning involving active students, whereas PBL class only reached slightly above the top threshold of the medium category. Furthermore, the conventional class had N-gain in low category, which is far below the threshold of medium category. This indicates that not all students have an expert attitude in problem-solving on the topic of the optical instrument. An expert student usually has an organized knowledge structure which enables them to solve the problem in a structural manner based on the related concept
[13]. On the other hand, there are students in the novice category in regards to their problem-solving ability on the topic of the optical instrument due to a weak understanding of the concept. These novice students indicate that they still have the low level of conceptual understanding, mathematical skill, and knowledge transferability in problem-solving [59]. The low level of conceptual understanding will affect the ability to solve problems because it’ll hinder the problem-solving process [60].

This study covers 5 topics in optical instruments, which are the human eye, magnifiers, camera lenses, microscopes, and telescopes. The N-gain score for each topic is presented in Table 7.

| Topics            | N-gain Classes (category) |
|-------------------|--------------------------|
|                   | Experiment 1 (n=38)       | Experiment 2 (n=38) | Control (n=38) |
| The human eye     | 0.15 (Low)               | 0.23 (Low)          | 0.22 (Low)     |
| Magnifiers        | 0.62 (Medium)            | 0.98 (High)         | 0.59 (Medium)  |
| Camera lenses     | 0.73 (High)              | 0.59 (Medium)       | 0.51 (Medium)  |
| Microscopes       | 0.34 (Medium)            | 0.40 (Medium)       | 0.13 (Low)     |
| Telescopes        | 0.35 (Medium)            | 0.16 (Low)          | 0.07 (Low)     |

Table 7 shows that students were able to improve their problem-solving skills in each topic, even though the improvements happened in varying categories. In all three classes, students had N-gain score in the low category in the topic of human eyes. This indicates that this topic was the most difficult to understand among others. On the topic of magnifiers and camera lenses, students had N-gain score in the high or medium category. This indicates that the two topics were relatively easier to understand than others. However, both Experiment classes had N-gain score in the medium category in the topic of microscopes, which is higher than the control class in the low category. It may have been caused by the different activities in each class, where Experiment 1 class designed and built microscopes, Experiment 2 class conducted an experiment on microscopes, and Control class only worked on written exercises. In the topic of telescopes, students in Experiment 1 class had N-gain score in the medium category, which is a level higher than Experiment 2 class in the low category. This may have been caused by the activity in Experiment 1 class which involves the students to design and build telescopes while the other two classes did not.

The effect size of students problem-solving skills in Experiment 1, Experiment 2, and Control class was analyzed. The result of the practical significance is presented in Table 8.

| Parameter | Pair of Classes |
|-----------|-----------------|
|           | Experiment 1 and Experiment 2 | Experiment 1 and Control | Experiment 2 and Control |
| d effect size | 0.59             | 1.75             | 1.41             |
| Category   | Medium           | Very large       | Very large       |

The pair of Experiment 1 and Experiment 2 class has the effect size in the medium category. This means that the implementation of PBL-STEM learning has the effect or impact in the medium category compared with PBL learning in regards to the increase in students’ problem-solving skill. However, both Experiment 1 and Experiment 2 classes has the effect size in the very large category compared with the Control class. This means that the implementation of both PBL-STEM and PBL learning has the effect or impact in the very large category compared with conventional learning in regards to the increase of students’ problem-solving skill

4. Conclusion
Based on the result and discussion, it can be concluded that the learning model influenced students’ problem-solving skills. Students which were learning using PBL-STEM (Experiment 1 class) had
acquired a significantly higher problem-solving skills than those who were subjected to PBL (Experiment 2 class) and conventional (Control class) models. Aside from that, students who were learning using PBL had acquired a significantly higher problem-solving skills than those who only studied in conventional models. Experiment 1 and 2 classes obtained an increase in problem-solving skills at a level higher than the control class. This research proved that the practical implementation of PBL-STEM model had a medium impact than PBL class. Furthermore, PBL-STEM and PBL had a very large impact, as compared with the conventional class, in increasing the students’ problem-solving skills.

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