The Building of Students' Problem Solving Skills through STEM Aproach with Virtual Simulation Media

The Building of Students' Problem Solving Skills through STEM Aproach with Virtual Simulation Media

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Abstract. The problem solving difficulty level of the topic of optics is ranked number two among other topics in physics, but the solution to this situation by implementing STEM approach with Virtual Simulation Media (VSM) in Problem Based Learning is still rarely done. This study aims to develop students' problem solving skills on the topic of optical instrument through PBL-STEM with VSM learning. The type of this research is a quasi-experimental with Pre- and Posttest Design, involving grade XI students in Malang, Indonesia. There are experiment and comparison classes, which received, respectively, PBL-STEM with VSM and PBL learning models. This study uses The Optical Instrument Problem Solving Skills Test with the alpha Cronbach reliability of 0.83. Data were analyzed using the Mann-Whitney U test and independent sample t test, N-gain, and effect size. The results showed that the students in experimental class had significantly better problem solving ability than the students in comparison class. PBL-STEM with VSM class has N-gain in medium category, while PBL class has low category. The two classes had the highest increase in the "useful description" step and the convex lens subtopic, and the lowest increase in the "logical progession" step and the telescope and camera subtopics. The PBL-STEM with VSM class has a practical effect of the "very large" category toward the PBL class in building problem solving skills. Therefore, research of Experiment-Comparison class pair is recommended to be widely implemented in schools as an effort to improve problem solving ability of student.

1. Introduction

Conceptual implementation of the topic of optical instruments on the field of technology, such as camera lenses, magnifiers, and telescopes, generally have contributed immensely to our daily lives [1,2]. The concept of optical instrument consists of the discussions about light as ray model and two laws of reflection and refraction [1,3]. However, students consider these concepts to be abstract in nature [4]. As a result, students can have misconceptions about the topic. For example, students think that mirror can produce real image [5]. Students also feel that Physics is a difficult lesson to study at school [6]. The topic of optical instrument especially belongs to 10% of the most difficult topic on the category of other topics in Physics on the National Examination on 2018/2019 year [7]. Few causes that are suspected to be the reason of the difficulty level of the topic of optical instrument are the abstract explanations by the teachers in class [6,8,9] and the high number of mathematical equations needed to help take care of the problems [10]. It's clear that this topic has few characteristics, which are related to daily lives problem, uses many mathematical equations, often used as technology, and

the abstract nature of the topic. These characteristics cause students to feel that the concept of the topic is difficult to understand.

The obstacles faced by students as mentioned above affect students' skills to help take care of daily contextual problems in the topic of optical instrument. Students which understand the concept of Physics will be able to solve problems in Physics because Physics learning is always related to problem solving [11]. Problem solving skill is one of the six research areas in the field of Physics learning [12] and it's highly needed in 21st century [13]. However, students' problem solving skill is still not yet optimal. A survey research stated that the difficulty level of the problem solving of the topic of optical instrument is ranked number two among other topics in Physics [14]. Problem solving ability of students is also low on other materials, for example Temperature and Heat [15], Heat and Energy [16], and Modern Physics [17]. It's clear that the optical instrument material is still rarely used as a topic in the research regarding problem solving skill.

There are still not many learning models to be implemented on some topics in order to enhance problem solving ability. Some of problem-solving models used in research, such as Moodle [18] and PBL-STEM in the Optical Instruments material [19], IBL-STEM in the Work and Energy material [20], and PjBL-STEM in the topic of Electomagnetic Induction [21], are able to increase problem solving skill. It's clear that the research about problem solving issues of the optical instrument topic which utilize the STEM approach alternative solution is still rarely done.

The STEM approach is one of learning approach which is able to enhance the skills of the 21st century [13,22,23]. The aspects of STEM, which are science, technology, engineering, and mathematics, are combined together into a whole learning process [24,25]. STEM approach can be integrated into Physics learning [26,27,28] so that the quality of learning process can improve [29,30] and the learning context can be more meaningful [31]. The STEM approach is very suitable with one of the characteristics of optical instrument topic, which is daily lives problem. To solve daily problems, STEM aids the students to work in a team to transform an unstructured tasks to be a well-structured outcome [32] so that students' knowledge and skill can develop comprehensively [33,34,35]. STEM appoach can make students' skill improve so they can plan, build, and utilize technology correctly so that their learning domain of affective, cognitive, and psychomotor can grow optimally [36] and STEM approach can make each student to be a more skillful solver of problem, creative inventor, and self-supporting learner [37]. It's apparent that students can be better in taking care of problems in daily lives in STEM approach.

When faced with contextual problems of daily occurence, most of the students still have difficulty in describing the problem, determining Physics concepts and applications, and choosing mathematical procedure [38]. The students often decide to directly use mathematical equations without understanding more about the problems they are working on [39]. This is made worse by teachers who don't give sufficient examples of practical problems in daily activities which are related to technology [40]. Also, teachers don't give enough exercise to train the ability of problem solving during learning process in class [41,42,43]. On the other hand, problem solving skill can be cultivated with the aid of learning model which puts emphasis on hands on activity [14]. Therefore, the presence of contextual problems which are related to technology and creation of engineering product in a learning is one of the best alternative to enforce hands on activity and trigger the growth of students' problem solving skill. The presence of contextual problems is one of the characteristics of problem-based learning [44] and the creation of engineering product is the characteristic of STEM approach [45]. This kind of learning is suitable with the characteristics of the topic of optical instrument, which is related with daily lives problem, many mathematical equations, and technology. However, research about the implementation of PBL-STEM approach to enhance students' problem solving ability on the optical instrument material are still rarely done.

Problem-based learning is student centered in nature because students are presented with real problems which can be encountered daily and are expected to solve them [46]. This way, PBL demostrates active learning and incites gain of knowledge, problem solving skills [47], and scientific process to grow [48]. The presentation of contextual problems in PBL can be linked with STEM with

the means of engineering activities [45]. The integration of STEM approach into PBL is forecasted to be successful to enhance problem solving ability of students.

The topic of optical instrument belong to the difficult category [7] and is abstract in nature [4]. This can trigger students misconception. Students who still have misconceptions about certain topic [49] and who don't have conceptual understanding on the optimal level [50] will consider Physics to be a difficult subject to learn [51]. On the other hand, Physics Education Technology (PhET) can be used to simulate the learning to be as similar as reality as possible as it can create the replica so students can experience more concrete learning experience [52]. Other than PhET, Ophysics and Macromedia Flash are other examples of the technology called virtual simulation media (VSM). VSM which is integrated into learning can enhance students' critical thinking skill [53]. However, STEM involves the process of critical thinking in the group of students as they endeavor into looking for the best solution to solve a certain problem [32]. Consequently, PBL-STEM model with VSM can be suitable to incite the growth of students' problem solving skill.

From the discussion above, it can be said that VSM which is aiding PBL-STEM can improve students' problem solving skills. Therefore, the objective of this research is to enhance problem solving ability of student in the optical intrument topic by investigating students' score in classes which are taught with PBL-STEM with VSM and PBL learning.

2. Method

This quasi experimental research uses Pre- and Posttest Design [54]. The subject of the research is 61 grade XI students in a high school in malang, Indonesia. The students are distributed into two classes: 31 students in Experiment class (PBL-STEM with VSM) and 30 students in Comparison class (PBL). PBL has 5 syntaxes [55], while problem solving skill has 5 steps, which are Useful Description (UD), Physics Approach (PA), Specific Application of Physics (SAP), Mathematical Procedures (MP), and Logical progreesion (LP) [11]. PBL-STEM with VSM learning is implemented to improve problem solving skill as elaborated in Table 1.

Table 1. The design of PBL-STEM with VSM learning to improve problem solving skills

No	PBL syntax with STEM approach	VSM	Steps of problem solving skill
1	Problem orientation (Science, Technology, Mathematic)	Explanation about VSM to students	UD
2	Organizing students to study (Science, Technology, Mathematic)	-	PA
3	Providing aid for individual or team investigation (Science, Technology, Mathematic)	Performing an investigation with the aid of VSM	SAP
4	Developing and presenting a product of creation and putting it on display (Science, Technology, Engineering, Mathematic)	-	SAP and MP
5	Analyzing and evaluating the process of problem solving (Science, Technology, Mathematic)	Analysing and evaluating with the aid of VSM	UD, PA, SAP, MP, and LP

It can be seen that STEM integration into PBL syntaxes with VSM is tailored to enhance the steps of problem solving ability. The dominan aspect of STEM approach is the aspect of engineering which has the following steps: identifying contextual problems, gathering information to look for the best alternative solutions, choosing one best solution, designing and making the product, testing the product, modifying or revising the product, and evaluating the whole process from the beginning to

the end [56]. Students in Experiment class make two engineering products, which are digital microscopes and simple telescopes, while students in Comparison class make one design of a product.

This research uses The Optical Instrument Problem Solving Skills Test in the form of 10 essay problems which covers 6 subtopics of optical instrumen [1] with the alpha Cronbach reliability of 0.83. Each essay problem contains 5 steps of problem solving [11]. Statistical analysis in this research utilizes few tests, such as Mann-Whitney U test and independent sample t test [57], N-gain [58], and effect size [57].

3. Result and Discussion

The average score and SD (in brackets) of pre-test data of Experiment and Comparison classes are, respectively, 6.75 (3.47) and 7.23 (2.34). It's shown that both classes have similar average score in pre-test. This means that both classes have same reference regarding the students' problem solving ability. The normality requirement test and variance homogeneity test show that pre-test data has normal distribution but doesn't satisfy the assumption of variance homogeneity. For this reason, the similarity test is done with Mann-Whitney U test which results in the finding that the pre-test data of both classes aren't significantly different. This means that both classes have same initial reference so that the presence or absence of difference of problem solving ability when the learning is done is only caused by the different treatment on both classes.

The average score of post-test and its standard deviation (in brackets) of Experiement and Comparison class are, respectively, 53.59 (10.63) and 27.44 (9.08). It's shown that Comparison class has lower average score than Experiment class. This means that students which were taught with PBL-STEM with VSM obtained better problem solving skill than students which were taught with only PBL model. The requirement test shows that post-test data satisfy the normal distribution test and variance homogeneity. For this reason, the difference test of post-test data is done with independent t test, which results in the finding that post-test data of both classes are significantly different. As the average score of Experiment class is higher than Comparison class, students in of Experiment class have higher average score of problem solving skill than students in Comparison class. In other words, the PBL-STEM with VSM model is able to cause students to have significantly better problem solving skill than PBL model.

The result of this reseach has provided proof that STEM approach in PBL can result in the significant enhance of students' problem solving ability. STEM approach can make students' motivation to significantly grow because it can unite the initially separated concepts to be used by students as an experience which is relevant to the phenomena in real world [59]. STEM approach is able to incite the growth of a skill to implement scientific and mathematic knowledge to solve daily problems with PBL model [60]. STEM approach directs students towards experiences which can be found on real world and high quality learning of science and mathematics so there is a chance for improvement of students' better achievements [61]. STEM approach is able to grow collaborative attitude so conceptual understanding can be shared by working together on a product design and eventually creating the engineering product [62]. The unity of aspects of science, technology, engineering, and mathematics in STEM approach become a bridge between students and real life problems which often happens on day-to-day activity so students' motivation on career and aspirations and their interest on science and mathematics can grow [37]. Indeed, PBL-STEM model can increase students' motivation so in time it can enhance and fortify daily life contextual problem solving ability of students [11].

In this research, students on PBL-STEM with VSM class made two engineering products, which are digital microscopes and simple telescopes, and the students of PBL class only stopped at making the design of a product. Students of Experiment class can modify or improve their products based on the feedbacks from other teams when they presented their products in class. Other than that, students of Experiment class also made a poster and written report about their products. Students in Comparison class only gained comments, critics, or feedbacks when they presented their design in the classroom. This difference in activity is what caused the different level of students' problem solving

skill between two classes, where students in PBL-STEM with VSM class are better than students in PBL class. STEM approach can give students experience on working on real life problems with the implementation of the principles of knowledge [63]. In PBL-STEM learning, students can develop the steps of problem solving skill [11]. It's clear that PBL-STEM model is effective in enhancing students' problem solving ability [64,65].

The result of this research also provides proof the important role of VSM in PBL in enhancing students' problem solving ability significantly. In Table 1, the first, third, and fifth syntax of PBL facilitate students by supporting them in learning with virtual simulation media. The use of computer based media can make the important role of teacher as facilitator more significant so that students' understanding towards the subjects in class can increase [66]. Virtual simulation media is a chain of program which visualize abstract phenomenon or experiment so that lessons in class can become easier, more interesting, and more interactive, and in turn can motivate students to improve their learning activity in order to develop the skills which are needed to solve various problems [67]. The findings of the research show that students who learned with PBL with the aid of VSM have better academic achievements than students who learned only with PBL [68]. The result of this research is consistent with the finding of previous research which stated that the problem solving skills of students who learned with PBL and ICT or VSM is significantly higher than students that are taught with PBL only [69] or with conventional model [70].

The increase of students' problem solving ability during learning is shown with the result of N-gain analysis. The analysis includes the increase of the total of test items number, every step of problem solving ability, every subtopic of optical intrument, and the easiest and the most difficult test item. The magnitude of the increase of the pre-test score to the post-test score is written in Table 2.

Table 2. N-gain result in Experiment and Comparison class

Parameter	Class	
	Experiment (n=30)	Comparison (n=31)
N-gain	0.502	0.218
Category	Medium	Low

Table 2 shows that Comparison class has N-gain on low category, or one level below the Experiment class on medium category. The increase of N-gain is in accordance to the research finding which stated that PBL-STEM with VSM model can improve problem solving ability students better than PBL model. Using the N-gain average threshold value of 0.48, which signifies the value that can be obtained in active learning [71], it can be seen that PBL-STEM with VSM class has surpassed the threshold while PBL class is still far below the threshold. This signifies that some of the students are expert on solving the problems in the topic of optical instrument and some of them are still on novice level. The expert students can organize the structure of the concept or the knowledge so they can solve problems also in structured manner [40]. On the other hand, the conceptual mastery, mathematical ability, and knowledge transfer skill of the novice students are still low so their ability to solve problems are hindered [72]. Indeed, low conceptual understanding can be an obstacle for students to solve problems well [73]. The gain of each step of problem solving skill is presented on Table 3.

Table 3. N-gain result of each step of problem solving ability

Class	N-gain of steps of froblem solving skills (category)				
	UD	AP	SAP	MP	LP
Experiment	0,85 (H)	0,57 (M)	0,33 (M)	0,49 (M)	0,31 (M)
Comparison	0,50 (M)	0,14 (L)	0,09 (L)	0,32 (M)	0,06 (L)

Table 3 shows that most of the steps of problem solving ability of Experiment class have the N-gain on medium category. Even one of the step, which is UD step, is on high category. Meanwhile,

most of the steps of problem solving skills of Comparison class belong in the low category. Overall, it can be seen that PBL-STEM with VSM class has N-gain increase on one level higher than PBL class. The two classes had the highest increase in the "useful description" step. This means that students have already possess decent basic ability to solve problems, which can be done by identifying important things so they can significantly mention the information and units relating to the problem [11]. However, the two classes had the lowest increase in the "logical progession" step. This means that students hadn't been able to identify and re-think of the problem and the solution which has been acquired [74]. The gain of each subtopic of optical instrument is presented on Table 4.

Table 4. N-gain result of each subtopic of optical instrument

Class	N-gain of subtopic of optical instrument (category)					
	Convex lens	Eye+ eyeglasses	Magnifier	Microscope	Telescope	Camera
Experiment	0.74 (H)	0.61 (M)	0.71 (H)	0.42 (M)	0.31 (M)	0.36 (M)
Comparison	0.41 (M)	0.36 (M)	0.35 (M)	0.23 (L)	0.06 (L)	0.04 (L)

It can be seen from Table 4 that Experiment class obtained the N-gain increase on high category for 2 subtopics and on medium category for 4 subtopics, while the Comparison class obtained the N-gain increase on medium category for half of the subtopics and low category for the rest. Overall, on each subtopic, PBL- STEM with VSM class had one level higher N-gain increase than PBL class. The two classes had the highest increase in the convex lens subtopic, and the lowest increase in the telescope and camera subtopics. Other than that, the N-gain of both classes on the subtopics of microscope and telescope is relatively lower than other subtopics. This is in accordance to the result of the interview with few Physics teachers, which stated that students have more difficulties on these two subtopics compared to others [75].

Regarding the N-gain of every test item, students in both classes acquired the biggest increase of problem solving ability on the test item number 4 about magnifier. This test item has cognitive level of analyze (C4), and indicator "It's presented a case of an archaeologist who has 2 magnifiers with different focal length to help see the very small writing on an inscription, the students can determine the appropriate magnifier with the desired lateral magnification results". This item requires students to apply the magnification formula M=(Sn/f)+1. The N-gain results for each step UP, AP, SAP, MP, and LP were 0.98, 0.90, 0.94, 0.90, and 0.72 respectively for the experiment class, and 0.87, 0.27, 0.16, 0.60, and 0.61 for the comparison class. It appears that at each step of problem solving ability, the experimental class students are superior to the comparison class. A very striking difference occurs in the AP and SAP steps. In this case, the experimental class students are much better able to determine the concept of magnification, and determine the mathematical formula equations to calculate the magnification. The STEM approach with VSM has been able to improve concept understanding and its application in magnifier technology.

Students in both classes have the smallest increase in problem solving ability in test item number 10 about the camera. This item has a cognitive level of evaluate (C5), and the indicator "It's presented a case for the use of focal length of a lens so that the resulting magnification is greater, students can analyze and determine the focus of the camera for a particular magnification". The solution of this problem requires understanding the formulas 1/f=1/s+1/s' and M=-s'/s. The N-gain results for each step UP, AP, SAP, MP, and LP are 0.78, 0.30, 0.11, 0.20, and 0.02 respectively for the experiment class, and 0.12, 0.00, 0.00, 0.00, and -0.14 for the comparison class. In this case, the experimental class students were far superior in all steps of the problem solvong ability than the comparison class students. In fact, in describing the steps of LP, the comparison class students were confused to conclude the relationship between the focal length of the camera lens and the resulting magnification so that the N-gain was negative. It is clear that in solving even the most difficult problems, the STEM approach with VSM is able to better provide students' understanding and concreting of abstract concepts.

The impact of STEM approach with VSM model towards students' problem solving skills is written in Table 5.

Table 5. Effect size analysis result of Experiment and Comparison classes

Parameter	Experiment and Comparison Classes Pair
d-effect size	2.642
Category	Very large

It can be seen from Table 5 that the Experiment-Comparison class pair yielded the effect size on the "very large" category. This is thought to occur because in making the product, students in the Experiment class complete the 7 engineering product design steps perfectly [56], while the comparison class students only use the design of a product step. With the results of the research on the effect size of this category, the wide implementation of the practice of Experiment-Comparison class pairs in schools is predicted to be able to give a very large impact in an effort to improve problem solving ability of students.

4. Conclusion

By referring to the previous discussion, a conclusion can be made that students' problem solving skills in Experiment class is significantly better than students in Comparison class. The treatment of STEM approach with VSM caused the increase in students' problem solving skills better than the learning method in Comparison class. PBL-STEM with VSM model had N-gain score in medium category, while PBL model had the score in low category. The two classes had the highest increase of problem solving skills in the "useful description" step which means that students had possessed a decent basic skill in solving problems which can be done by identifying important things to name significant information and units in a problem. However, the two classes had the lowest increase in the "logical progession" step which means that students still hadn't been able to define and re-think of a problem and the solution which they had obtained. The two classes had the highest increase of problem solving skills in the convex lens subtopic and the lowest increase in the telescope and camera subtopics. It is recommended that this research to be implemented in real world class setting because the PBL-STEM with VSM class had a practical effect in the "very large" category toward the PBL class in building students' problem solving skills.

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