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The Development of Dual Mode Experiment Model Based on Physics Problem Solving:

Comparing learning achievements between real and virtual experiment

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***Abstract*—Experimental models based on physics problem solving to enhance critical thinking and problem solving skills (CTS and PSS) have been successfully developed, both real and virtual experiments. The experimental stages consist of problem descriptions, understanding problems, method questions, predictions, determining ideas, equipment, procedures, measurements, data analysis, conclusions, and presentations. During the experimental process, real experiment mode uses real equipment, while virtual experiment use computer simulations. Each experimental mode was tested on prospective physics teachers at a university in Bengkulu, Indonesia. A total of 20 students (7 men and 13 women) were involved in real experiments, and 21 students (6 men and 15 women) were involved in virtual experiments. Before and after conducting experiments, students in both experimental groups were given CTS and PSS tests. The pretest scores of the two experimental groups were not significantly different. After conducting experiments, both groups were given posttest. The mean score of CTS and PSS posttest for the real experiment group was 77 and 79, while the virtual lab group was 78 and 81. It can be concluded that the two experiment models have equivalent ability in increasing CTS and PSS students.**

Keywords*—*dual mode experiment; physics problem solving; real experiment; virtual experiment; critical thinking; problem solving

I. INTRODUCTION

Experiment activities have an important role in the curricula of science education both at the school and higher education levels. Experiment activities in the laboratory not only can help students understand the theory they learn in the classroom, but can also stimulate students' conceptual changes in a more scientific direction [1]. In a more specific aspect, problem solving based experiment can be used to improve higher order thinking skills such as critical thinking, problem solving, creative thinking, and decision making skills [2].

Studies on the effectiveness of experiment activities to improve students' thinking skills have been widely carried out, for example by Fuccia et al. [3] and Malik et al. [4]. Based on the results of the study, the researchers recommended that the traditional experiment model commonly applied in the science education environment be replaced by an experimental model based on higher-order thinking skills [5].

Although researchers and science teachers agree that experiment activities cannot be separated from science classes, in reality teachers still often face obstacles and challenges in conducting experiment. The most frequently experienced obstacle is the lack of availability of experiment equipment in the laboratory, the low knowledge of teachers about experiment models, the inability of teachers in designing experiment based on high-level thinking skills, and limited time allocation of physics learning [6]. It is causes the implementation of physical experiment in many schools to be in the low category, with traditional experiment models [6].

There are several alternative solutions that can be applied to overcome these obstacles and challenges. First, the lack of availability of experiment equipment and the limited time for learning that is not accommodative to the implementation of experiment can be overcome through the application of virtual lab or virtual experiment. The use of virtual experiment has been proven to reduce consumption time experiment, improve understanding of students' physics concepts [7-9], and have the same effectiveness as real experiment in improving students' physics learning achievement [10-12]. Second, the use of traditional experiment models that lack emphasis on thinking activities can be overcome by applying the problem solving experiment model so that it has the potential to be able to train high-level thinking skills.

Many studies have been carried out on the application of virtual experiment assisted by computer simulations, for example by Martinez et al. [13], Ince et al. [14], Ekmekci and Gulacar [15], but virtual lab models have not been found that are intentionally designed to develop skills. high-level thinking. Development of a problem solving based experiment model has been done by Heller and Heller [16], however, this model is only oriented to train problem solving skills and concept understanding only, not yet covering other aspects of higher level thinking skills. In addition, the experiment model is only effective for macroscopic concepts, and is less adaptive to abstract and microscopic concepts.

This study developed a problem solving based physics experiment model, both for hands-on experiment in laboratories and virtual experiments using computer simulations. The experiment model developed was designed to train critical thinking skills and problem solving physics of prospective teacher students. The experiment model developed hereinafter referred to as dual mode of experimental model based on physics problem solving.

II. Method

The research aims to develop dual mode experiment model based on physics problem solving through research and development method with 3D model consisting of define, design and develop stage. The define stage consists of reference studies and need assessment, a context analysis for the importance of developing the dual mode experiment model. Reference studies contain literature analysis and similar research. Need assessment activities are conducted in the form of a study to explore the profile of physics experiments at one of the universities in Bengkulu, Indonesia. Instruments used in the need assessment stage are experimental activity observation sheets, questionnaire and document review sheet.

The design stage contains the activities of formulating and defining the experimental stages, design of the experimental worksheet that represents the characteristics of the dual mode experiment model. The design stage is based on the results of reference studies in the previous stage related to problem solving experimental models. The final result of this step is the design of the experiment stages and experimental worksheet.

The development stage is the realization of the conceptual framework obtained at the design stage into the product form. Activities at the development stage consist of learning objectives, developing dual mode experiment model represented through experimental worksheets, developing research instruments that will be used to assess the achievement of learning objectives, validation of experiment model through expert review, and implementation of the dual mode experiment model. The expert review and field trials results was used as a reference to refine the experiment model. The instruments used in the develop stage include expert review sheets, experimental worksheets, experimental observation sheets, problem solving and critical thinking skills test, and student response questionnaires on the application of the experiment model.

The implementation phase of the experimental model was conducted in two intervention groups, one group was treated in the form of problem solving based hands-on experiment (called HLPS group) and the other group in the form of problem solving based virtual experiment (called VLPS group) on the concept of dynamic electricity. The PSHL group consists of 20 students (7 men and 13 women) and the VLPS group consists of 21 students (6 boys and 15 girls). Before and after conducting experiments, each group was given a test of CTS and PSS. Experiment implementation in each experiment mode is guided by experimental worksheets.

III. Results and Discussion

A. *Define Stage*

The define stage contains preliminary studies to obtain rationality for the development of dual mode model based on problem solving experiments. At this stage need assessment and reference studies are carried out. The need assessment consists of implementation studies and physics experimental models, as well as the profile of debriefing of high-level thinking skills through physics experiments that have been carried out. Meanwhile, reference studies contain literature review related to higher order thinking skills, problem solving laboratories, virtual laboratories, problem solving skills, and critical thinking skills.

In the need assessment study, some data and information were obtained which showed that the physics experiment which had been carried out in one of the universities in Bengkulu, Indonesia, was in the moderate category, the dominant experimental model was verification experiment (traditional model), basic experimental equipment owned is in the moderate category while advanced experimental equipment is in the low category, debriefing high-level thinking skills through experimentation is in the low category, the experimental model used has not been intentionally designed to provide higher order thinking skills. In addition, it is known that the critical thinking and problem solving skills of pre-service physics teachers in that university are still in the low category [6].

In the reference study obtained a laboratory activity model that were used as a reference for the development of experimental stages in the dual mode model experiment, namely the problem solving laboratory model developed by Heller and Heller at Minesota University [16]. Computer simulations used as equipment in virtual experiment mode are PhET simulations that are downloaded from https://phet.colorado.edu/.

Indicators of critical thinking skills used in the adoption of the Halpern critical thinking framework [17], and indicators of problem solving skills used were derived from the problem solving framework Heller et al. [18]. The results of the preliminary study show the importance of experimental models of development based on problem solving to improve the quality of physics learning process through experimental activities, especially to developing critical thinking and problem solving skills.

B. *Design Stage*

The design stage contains experimental stages based on physics problem solving, both in HLPS and VLPS modes; experimental worksheet; expert review sheet; and designing evaluation tools to assess the objectives of developing experimental models in the implementation stage. The experimental stages based on problem solving consist of the pre-experimental phase, the experimental phase, and the post-experimental phase. The pre-experimental phase was done collaboratively outside the classroom before the experimental activities were carried out, while the experimental and post-experimental activity phases were carried out collaboratively in the laboratory. Experimental stages in each phase are shown in Table 1.

TABLE I. STAGES OF PROBLEM SOLVING-BASED EXPERIMENTS

No	Phase	Experiment Stage
1	Pre-Experiment	Problem context, understanding problems, method questions, group predictions, determining ideas
2	Experiment	Tools and materials, procedures, measurements, data analysis, conclusions
3	Post-Experiment	Presentation of experimental results

The problem context is a description of the problem that must be solved by students through experimental activities. The context of the problem contains problems related to students' daily lives related to the concept of dynamic electricity. Problems are presented in the form of story problems, students are made as the main character who seems to face these problems. At the end of the story problem are given some ideas or ideas that might lead to solutions to existing problems. Students are asked to evaluate all existing ideas and choose one of the ideas that can lead to solving the problems at hand.

At the beginning of each experimental stage, it is planned to contain brief instructions related to activities that must be done by students at this stage. Each stage of the experiment contains guiding questions that can guide / guide the activities that must be done. Students must answer each question. In addition, the guiding questions are oriented to provide indicators of critical thinking skills and predetermined problem solving.

C. Develop Stage

The develop stage contains the realization of the experimental model design into the product of a problem solving based experimental model, in the form of experimental worksheets both HLPS and VLPS models. This stage produces the context of the problem and the guiding questions of the experimental activity that are the most important part of the experimental worksheet.

The context of the problem is used to relate to the application of the concept of dynamic electricity on real world problems. In the context of the problem, it was told that the ship of a group of students was stranded on a remote island due to extreme weather when they were fishing in the sea. To ask for help, they must be able to generate SOS signals. Next they make an electrical circuit to generate SOS signals, unfortunately the circuit made has not been able to generate a signal so it must be modified. The challenge faced was to determine what devices and how to be added to the circuit in order to generate SOS signals, while the equipment in the ship was very limited.

The dual characteristic in the mode of experiment models based on problem solving is different from the problem solving lab (PSL) developed by Heller and Heller [16]. In the dual mode of experiment model, there are ideas that can be considered by the student to solve the problems. There is one idea that can be used to solve the problem. Students should be able to evaluate and find that idea. Students can find data's and supporting information through the questions in the stage of understanding the problem and the question method. These questions can lead to the observation and measurement plan, and analysis of data. After the students have answered all the questions, they must decide what ideas will be used to get the solution to the problem. Right or wrong the chosen idea can be known after experimental data are obtained.

The exploration stage of the PSL model contains instructions and safety warnings on equipment, instruction on experimental activities to be performed, and contains brief questions to confirm what students have done and to guide what activities the student should take in measuring [16]. In the dual mode experiment model, the exploration stage is renamed to the experimental procedure stage. This stage does not contain instructions on what the student should do, but only contains guiding questions that can lead to the ability to formulate the experimental steps that will be used to collect data during the data collection stage.

The dual mode experiment model based on physics problem solving uses the term measurement for the activity of finding or measuring independent variables. At this stage student conduct measurement and observation activities (especially for VLPS experiment mode) to collect data that can lead to problem solving. The data obtained at the measurement stage are then organized in a table of measurement results. The data that has been organized will be analyzed at the data analysis stage.

The experimental worksheet that represents the experimental model based on physics problem solving is further studied by three physics-based learning experts based on established criteria. The suggestions provided by experts are used to improve the experimental model produced. After the revision process, the dual model mode of experiment based on physics problem solving was tested on a limited sample (N = 15) which served as a model readability test. The results of the expert review and the readability test of the model are used as guidelines for revising the model. Revisions are made to elements that still need strengthening. The final result of the revision process is obtaining an experimental model of physics problem solving that is ready to be implemented in experimental activities

D. Experiment Model Implementation

The implementation of the experimental model that was obtained was carried out on 20 students for the VLPS experimental model and 21 students for the HLPS experimental model. Both groups carried out experiments at the same time and time range (8am - 10am). The VLPS group conducted experiments in the computer laboratory room and the HLPS group conducted experiments in a physics laboratory. Before the model is implemented, an initial measurement of CTS students and PSS was performed using essay test. Furthermore, students follow experimental activity using a model based on physics problem solving experiment. After the experimental activity is completed, the final measurement of students is done using the same test instrument. Improved students' CTS and

PSS scores both groups of students after participating in the experimental activities were compared.

The mean CTS and PSS test scores for both HLPS and VLPS groups are shown in Table 2. It can be seen that the pretest scores of critical thinking skills and problem solving are still low when compared with a maximum score of 100. Based on the results of different test two mean two independent samples it is known that the average pretest scores of the two groups of students were not significantly different, both CTS and PSS test. The low level of critical thinking skills and problem solving corresponds to previous studies which showed that critical thinking skills and problem solving for students at university was still in the low category [19]. Meanwhile, based on the results of the non-parametric test using SPSS 22 on the average score of the two groups ($\alpha = 0.05$), the results showed that the posttest scores of the two groups of students were not significantly different (*p-value = 0.13*).

TABLE II. AVERAGE SCORE OF STUDENTS ON CTS AND PSS TEST

Experiment Groups	Pretest/Posttest	CTS Test	PSS Test
HLPS	Pretest	38	43
	Posttest	77	79
VLPS	Pretest	39	42
	Posttest	78	81

The scores of the pretest and posttest for each student were then used to calculate the normalized gain score (<*g*>). Based on the results of calculations obtained that generally students in the two experimental groups have obtained additional scores with a high category. The percentage of students who get <*g*> with a high category is shown in Table 3.

TABLE III. PERCENTAGE OF STUDENTS WITH <G> IN A HIGH CATEGORY ON CTS AND PSS TEST

Experiment Groups	CTS Test	PSS Test
HLPS	80%	85%
VLPS	86%	90%

The number of students who received a high <*g*> category in both groups of students for both types of tests was greater than 75%, this indicates that the experimental model based on physics problem solving has good effectiveness in improving critical thinking skills and student problem solving. This result is in accordance with the findings of previous researchers who found that the use of real problems in experiments can promote the higher-order thinking skills of students [20-22]. These findings indicate that the provision of contextual problems in learning can stimulate the development of lower-order thinking skills towards higher-order thinking skills.

IV. CONCLUSION

The experimental model based on physics problem solving has been successfully developed, both the hands-on lab and virtual lab versions. The experimental stages consist of the problem description, understanding the problem, method questions, group prediction, determining ideas, tools, procedures, measurements, data analysis, conclusions, and presentation of results. These stages are grouped into the pre-experimental phase and the experimental activity phase. Based on the results of the dual mode model based on physics problem solving experiment implementation in learning, it was found that the hands-on lab and virtual-lab versions have the same effectiveness in improving critical thinking skills and problem solving for physics teacher candidates. Thus it can be concluded that the experimental model produced can be used as an alternative to laboratory activity models that can improve critical thinking and physics problem solving skills.

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