The development of cooperative problem solving physics laboratory model on simple pendulum concept

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Abstract. This study aims to develop a model of laboratory activity based on problem solving called cooperative problem solving physics laboratory (CPSPL) model. The study was conducted at a university in Bengkulu, Indonesia. This study uses research and development method with 3D model consisting of define, design, and develop stage. The define stage contains a preliminary study aimed at exploring conditions that encourage the development of the CPSPL model. The design stage contains the activity of planning the CPSPL model syntax and the experimental worksheet. The development stage contains the activities of realizing a conceptual framework in the form of a CPSPL product. At this stage the CPSPL model is validated by experts (N=3) and implemented to the pre-service physics teachers (N=40) which have been grouped into three initial problem solving abilities, namely high, medium and low level. After implementation, a final problem solving skill test is performed. Based on the data analysis, it was found that the improvement of students’ problem solving skills in the three groups are in good category and not significantly different. It can be concluded that the CPSPL model can be used to improve the problem solving skills of pre-service physics teachers.

1. Introduction

Experimental activities are an important part of physics learning which can provide students with direct experience in applying scientific methods. The experimental activity in the laboratory is an important vehicle in constructing, reconstructing, and verifying physics concepts learned in the classroom [1]. In addition, experiments can also encourage and facilitate conceptual development. Experiments have an important role in physics learning, therefore experimental activities can not be separated from classroom learning. Nevertheless, the implementation of physics experiments at the school and higher education levels often encounters many obstacles and challenges that are less able to provide benefits to students.

The main constraints of teachers in organizing physics experiments are the lack of available experimental equipment and the lack of representative laboratory space. In addition, experiments that have been successfully performed generally emphasize only the technical activity of the laboratory rather than the thinking activity. Students are generally busy with equipment assembly activities and make measurements using the detailed procedures contained in the experimental guidelines. Students such as robots who must perform a series of activities following procedures established by the teacher. Such experiments are characterized by low metacognition activity. As a result, students do not have the opportunity to develop thinking skills and solve problems by using various problem-solving strategies.
It takes a model of physics experiments that emphasizes more on thinking and problem solving activities. Such models can encourage the improvement of thinking skills from low levels to higher-order thinking skills. Problem solving-based physics experiment models are still rarely developed. One of the problem solving-based experiment models is the problem solving laboratory [2]. Problem solving laboratory model (PSL) consists of two main stages of pre-laboratory and laboratory activity. The pre-laboratory stage consists of general explanatory stage, objectives, preparation, problem, equipment, prediction, and warm up question. While the laboratory activity stage consists of exploration, measurement, analysis, and conclusions. The problems used in experiments are described in the context of the daily life-related problems associated with the physics concept. Students are asked to provide problem solving predictions, formulate experimental steps to find solutions, organizing data, analyse the data, and make conclusions.

Although the PSL model is claimed to be used to improve students’ problem solving skills, few teachers have implemented the model yet. Some of the reasons put forward are that teachers find it difficult to design and implement the PSL model. Stages in the PSL are not easy to understand and implement. Implementation of the PSL model also requires more time consumption than the verification experimental model. Based on some of these constraints, this research developed cooperative problem solving physics laboratory model (CPSPL) based on the process of presence and modification of PSL model. The CPSPL model has a simpler, easier to understand, and can represent a problem-solving strategy. Each stage of the CPSPL model contains questions that can lead students to problem solving activities.

2. Theoretical framework
Simple pendulum is one example of simple harmonic motion. A simple pendulum consists of a lightweight rod and a small ball (pendulum) of mass m that is suspended at the end of the rod along L. A simple pendulum movement is analyzed by ignoring the air friction and rod mass. The force acting on the pendulum is the gravity force w and tension force Fr. The gravity has a component of mg cos θ which is in the direction of the rope and the mg sin θ is perpendicular to the rope. The pendulum can oscillate due to the gravitational component of mg sin θ which acts as the restoring force. Since there is no air friction force, the pendulum oscillates along a circular arc with a fixed amplitude. The simple pendulum period (T) can be determined using equation (1), where g is the acceleration of gravity [3].

\[ T = 2\pi \sqrt{\frac{L}{g}} \]  

3. Method
The research aims to develop CPSPL model 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 CPSPL 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 high school level and physics education courses 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 (model syntax), design of the experimental worksheet that represents the characteristics of the CPSPL model, plan learning objectives and the physics concepts to be used in the experimental worksheet. 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 CPSPL model syntax and the experimental worksheet to be used.

The development stage is the realization of the conceptual framework obtained at the design stage into the product form of the CPSPL model. Activities at the development stage consist of setting learning objectives, developing CPSPL model represented through experimental worksheets, developing research instruments that will be used to assess the achievement of learning objectives, validation of
CPSPL model through expert review, and implementation of the CPSPL model in physics experiments. The expert review results and field trials are used as a reference to refine the CPSPL model so that it is ready to be implemented more widely. Learning instruments used in the development stage include expert review sheets, experimental worksheets, experimental observation sheets, problem solving skill test, and student response questionnaires on the application of the CPSPL model.

4. Result and discussion
The development of the CPSPL model starts from the define stage. The main activities included in this stage are reference studies and need assessment. Reference studies contain literature review related experimental models, problem solving-based experiments, problem solving learning models, and problem solving skills. Reference studies are also conducted in the form of analysis of international journals related to similar research. Some of the results obtained in the reference study are (a) the description of experimental stages based on problem solving which will be the basic reference for the development of CPSPL model, (b) obtained information that the use of contextual problems into the classroom or laboratory can train students problem solving skills, and (c) obtained information that the development of physics experiment based on problem solving lab and its implementation on learning has not been done by researchers and teachers.

Need assessment at the define stage is done through a study of the profile of physics experiments in 8 high schools and a physics education program at a universities in Bengkulu Province. The aspects of the experiment that are explored are support resources, implementation, obstacles, assessments, experiment models, and skills training of the 21st century through experiments. Based on the results of this study, it is described that the resources that support the implementation of physics experiments are in moderate category; the implementation of the physics experiment is in the less category; the main obstacle experienced by the teachers are the difficulty in designing the experimental activities and technical implementation, and minimal equipment availability; the dominant experimental model used is expository; and problem solving skills training through physics experiments is in moderate category [4,5]. The results obtained in accordance with previous findings indicate that the experiments are rarely performed in some high schools, the experimental model used is the expository model [6]. In addition, it is known that the problem solving skills of pre-service physics teachers in a university are still in the low category [7]. The results of the needs assessment show the importance of experimental model development based on problem solving lab to improve the quality of physics learning process through experimental activities, especially to provide problem solving skills.

The results of reference studies that have been done in the define stage serve as the basic reference in formulating the CPSPL model at the design stage. The CPSPL model syntax is adapted from the PSL model stages that have been developed by Heller and Heller at the University of Minnesota [2]. The stages in the CPSPL model consist of the problem description stage, problem understanding, method questioning, evaluation and selection of ideas, equipment and materials, procedures, data collection, data analysis, and conclusions. Some of the predefined CPSPL model that have been set are (a) the problem used described in a context related to daily experience related to physics concepts, (b) In the context of the problem given some alternative ideas that may be chosen by the students to solve the problems, (c) Each stage in the CPSPL model contains guiding questions that will direct the student to the experimental activity, (d) the guided question provided will encourage the students to implement the problem solving strategy, and (e) the CPSPL model is represented in the form of an experimental worksheet.

The conceptual framework of CPSPL model design that has been formulated at the design stage is developed in the form of CPSPL model product at the develop stage. At this stage, the experimental worksheet will be developed which will guide the students during the experiment using the CPSPL model. The worksheet contains 9 stages of experimental activity grouped into pre-laboratory and laboratory activity phases. The pre-laboratory phase consists of the stage of problem description, problem understanding, method question, and evaluation and selection of ideas. While the laboratory
activity phase consists of the stage selection of equipment and materials, experimental procedures, data collection, data analysis, and conclusions.

The activities of the students in the pre-laboratory phase are carried out before the experimental activity in the laboratory. The pre-laboratory stage is done in a cooperative group consisting of 2-4 students. Pre-laboratory phase is intended for students to read and understand the problems faced, answering method questions to get an overview of the experimental procedure plan, data analysis plan, and planning the right ideas to solve the problems encountered. Phase of laboratory activity is done in physics laboratory, students are involved in the activity of determining and choosing the necessary equipment, formulating the experimental steps to be used to collect data, collecting data through measurement and observation, organizing data in the form of appropriate representation, and make a conclusion.

In the developing stage, the context of the problems and the guiding questions at each stage of the experiment are developed. In this paper, the context of the problem used relates to the application of the concept of simple pendulum on everyday problems. The description of the problem is shown in figure 1. The problem characteristic in CPSPL model is different with PSL model. In the CPSPL model, there are several solutions in the form of ideas that can be selected by the student to solve the problems encountered. Among the ideas offered, there is one idea that can be used to solve the problem. Students should be able to find the idea by analyzing and evaluating all evidence or supporting information. Students can find supporting information and data through questions in the stage of understanding the problem and the method question stage as shown in figure 2. These questions can help the students to understand the main problem faced, can lead to the measurement plan, observation, and analysis of data to be performed. Sometimes students have to do simple practice to get the answer. After the students have answered all the questions, they must decide what ideas will be used to get the solution to the problem. The idea chosen represents the group's prediction of the experimental results to be performed. The predicted truth will be confirmed at the conclusion stage.

Problems Description Stage

You and your friends are doing fieldwork in a geophysical company. The head of the company obtains information that the precipitation of iron ore or petroleum in a particular place of different density with the surrounding materials will affect the acceleration value of gravity \( g \) at the site. Thus, the results of \( g \) measurements in the area under investigation can provide important information about the precipitation properties present in the area. The head of the company wants to prove the truth of the information and assign your group to investigate the nature of the sediment in an area suspected of containing petroleum. Before measuring gravity into the field, your group decides to determine how to measure \( g \) through a simple pendulum experiment involving the variable length of the pendulum \( l \), the pendulum mass \( m \), the swing angle \( \theta \) and the square of the pendulum period \( T^2 \). Next will investigate how to determine the acceleration of gravity based on the curve of the relationship between possible variables.

Before you start modeling, you ask your group members to state their ideas about how the most appropriate physical pendulum model is used. Their ideas are: (1) Jack argues that the length of the rope and the pendulum mass used must be kept constant and the angle of the pendulum swing must be varied, this pattern will give the actual gravity acceleration value. The value of gravity can be determined by the relationship curve between the length of the rope and the angle of the pendulum. (2) Agnes argues that the length of the rope and the angle of swing must be kept constant, while the pendulum mass must be varied so that its influence over the period of the swing can be known. The value of gravity acceleration can be determined through the curve of the relationship between the pendulum mass and the square of the pendulum period. (3) John argues that the angle of the swing must be made small enough, the mass of the pendulum is fixed, while the length of the pendulum must be varied to know its effect on the pendulum swing period. The value of gravity acceleration can be determined by the relationship curve between the length of the rope and the square of the pendulum period.

Figure 1. Problem description on CPSPL model.
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. In the CPSPL 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.

**Understanding Problem Stage**

Before taking measurements to the field, you should really understand the problem. To find out the extent of your understanding of the problem, answer the following questions:

1. Can you summarize the problem with your own words? What are the main issues to solve?
2. What variables are involved in the problem? For each of your ideas, can you determine which independent variables, dependent variables, and control variables?
3. What physics concepts are involved in the problem?
4. Can you draw a physical sketch of a simple pendulum system that you will use in your experiment?

**Method Question Stage**

The following questions can guide you in choosing ideas and planning actions to solve problems.

1. How to sketch the forces that work on the pendulum when the maximum swing occurs?
2. Which physics principles are appropriate for this situation?
3. Can you find the equation to determine the pendulum period? How is the equation?
4. How to determine the pendulum period using stopwatch?
5. Does the length of the rope, the pendulum mass, and the angle of the swing (θ) affect the pendulum period?
6. If the length of the pendulum A (l_A) is shorter than the length of string B (l_B) then each pendulum swings with angle θ (no more than 15°) with the same mass m in the same time, whether the length difference of the rope affects the period (T)? Which pendulum period is greater?
7. How to determine the acceleration of gravity (g) based on the graph of the relationship between l and T^2?

**Figure 2.** Guiding questions at the stage of understanding problem and method questions.

The measurement stage of the PSL model contains the measurement activity using the existing equipment to obtain the value of the dependent variable. The CPSPL model prefers to use data collection terms rather than measurements. Data collection activities include measuring physics, observation, and organizing data in the form of appropriate representation. The data that has been organized is then analyzed to facilitate the process of interpretation of the experimental results.

The experimental worksheet that represents the CPSPL model is further validated by three physics-learning experts. The criteria used as the basis for the assessment are the suitability of the experimental activities with learning objectives, the suitability the context of the problems used with the objectives of the experiment, the suitability of the model syntax with the stages of problem solving strategies, ability of questions given at each stage in directing students to implement problem-solving strategies, the suitability of the experimental activity with the explored physics concepts, and the readability aspect or ease of the experimental worksheet to be understood. Expert validation results on the CPSPL model on the topic of physical pendulum is in good category.

After a valid prerequisite is reached, the next step is to implement the CPSPL model on the physics learning. Implementation was performed on the students (N=40) who were following the school physics experiment course. Before the model is implemented, an initial measurement of student problem solving skills is performed using the problem solving skills test instrument. Furthermore, students follow experimental activity using CPSPL model. After the experimental activity is completed, the final measurement of students’ problem solving skills is done using the same test instrument. Improved students’ problem-solving skills scores after using the CPSPL model (experimental class) were then
compared with the score of control class students (N=35) who followed the experiment using the expository model.

The initial and final scores of problem solving skills of the experimental class students obtained through the tests are 42 and 81 respectively, while the control class student scores are 43 and 70. Based on the result of t-test on the significance level \( \alpha = 0.05 \), it is obtained that the final scores of the two student groups differ significantly (\( p\)-value = 0.00). The students' experimental class scores was significantly higher than the control class. In addition to these tests, the initial scores of students before attending learning with the CPSPL model were categorized into high, moderate, and low ability groups. Based on the initial and final scores obtained, the students’ problem-solving skills of three groups can be determined.

The difference in the score of three groups of students was analyzed using one way anova test, it was found that the improvement of problem solving skills from the three groups did not differ significantly. These results indicate that the CPSPL model can be used to improve student problem-solving skills at all levels of ability. 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 [8,9,10,11]. In addition, students have responded positively to the implementation of the CPSPL model in physics experiments.

5. Conclusion
The CPSPL model development procedure has followed the experimental model development procedures generally conducted by the researchers. The CPSPL model is represented in the form of experimental worksheet that can be applied to basic physics concepts. The CPSPL model consists of stages of problem description, problem understanding, method question, evaluation and selection of ideas, selection of equipment and materials, procedures, data collection, data analysis, and conclusions. Implementation of CPSPL model in physics experiment can be used as an alternative model to improve students’ problem solving skills.

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