The development of higher order thinking virtual laboratory on photoelectric effect

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Abstract. Higher order thinking skills (HOTS) are potentially developed through physics laboratory activities intentionally designed to develop these skills to the students. This study aims to develop higher order thinking virtual laboratory (HOT-VLab) model on photoelectric effect concept to improving critical thinking skills (CTS) and students’ creative problem solving skills (CPSS). The research method used is research and development with ADDIE model. Validation of HOT-VLab model has been done through expert review by physics learning expert (N=3). HOT-VLab model is implemented to a number of pre-service physics teachers (N=35) at a university in Bengkulu, Indonesia. The CPS and CPSS tests were performed both before and after the HOT-VLab model implementation to determine the CPS and CPSS enhancement obtained by the students. The results of the test data analysis show that the CTS and CPSS scores of students increased with N-gain are 0.54 and 0.53. Both N-gain scores have moderate category. In addition, it was found that the pretest and posttest scores of both types of tests are significantly different. It can be concluded that HOT-VLab model can be used to improve students’ HOTS.

1. Introduction
Higher-order thinking skills (HOTS) are defined as those of cognitive skills that allow students to function at the analysis, synthesis, and evaluation levels of Bloom’s [1]. HOTS are grounded in lower order skills such as discriminations, simple application and analysis, and cognitive strategies and are linked to prior knowledge of subject matter content. HOTS include critical, logical, reflective, metacognitive and creative thinking [2]. In this paper, HOTS are defined as a cognitive skill in the form of critical thinking skills (CTS) and creative problem solving skills (CPSS). HOTS can be promoted through learning using specific learning materials and methods. In science learning, HOTS potential to be promoted through laboratory activities [3].

Laboratory activities have important role in science learning, including physics. Laboratory activity in physics learning is often referred to as experiment, hands-on lab, practicum, or laboratory practice. These terms refer to a series of student activities in the observation, measurement, collection and analysis of data, and draw conclusions in the laboratory using certain equipment and materials. Laboratory activities serve as a vehicle for constructing, reconstructing, verifying, and strengthening
scientific knowledge [4]. Laboratory activities can be used to train basic experimental skills and scientific methods [5]. Proper laboratory activity can stimulate the development of low-order thinking skills (LOTS) to HOTS [6].

The ability of a series of laboratory activities to promote HOTS is strongly influenced by the design of laboratory activities. One of laboratory design that can be used to promote HOTS is the problem solving-based laboratory design [3]. This design is characterized by the giving of contextual problems related to a particular concept of science [7]. Problem solution can be obtained through a series of experimental activities. The contextual problems contained in the lab design serve as drivers that can encourage student involvement in a series of investigations using their own procedures to solve the problem. The problem-based laboratory design encourages students to think independently and discard the laboratory manual.

The problem solving-based laboratory design that has been successfully developed by researchers is problem solving laboratory (PSL) model at the University of Minnesota [7] and the higher order thinking laboratory (HOT-Lab) model at Universitas Pendidikan Indonesia [8]. The PSL model was developed to promote students problem solving skills, while the HOT-Lab model was developed to promote critical thinking and problem solving skills. Although in test implementation both models can improve critical thinking and problem solving skills but both models are only effective to explore macroscopic physics concepts, and less suitable for microscopic physics concepts. Though the characteristics of physics concepts that are abstract and microscopic is very potential to promoted students’ HOTS. Therefore, a new laboratory model is required that is not only suitable for abstract and microscopic concepts, but also reduces time consumption, promote students’ ICT literacy, and can tackle the broader aspects of HOTS. This study aims to develop higher order thinking virtual laboratory (HOT-VLab) model on photoelectric effect concept to improving critical thinking skills (CTS) and students’ creative problem solving skills (CPSS). HOT-VLab is an alternative model of laboratory activities that can be used to improve students’ HOTS through physics concepts that have high levels of abstraction.

2. Theoretical framework
The photoelectric effect is an important concept in physics that can facilitate students’ ability in understanding the concepts of quantum physics. The phenomenon of the photoelectric effect encourages the emergence of the concept of light dualism, the light of a time can behave as a wave and at other times can behave as particles. In the photoelectric experiment, it is found that the electrons can emit from the surface of a metal when the metal is irradiated with a light having a certain frequency. The magnitude of the photoelectrons’ kinetic energy ($E_K$) produced is influenced by the magnitude of light photon energy and the work function of the corresponding equation (1) with $hf$ is the energy of the light photon and $w$ is the work function of the metal material [9].

$$E_K = hf - w \quad (1)$$

Photoelectric effect experiments have an important role in physics learning considering this concept is the basis of the concepts of modern physics. However, to be able to do photoelectric experiments required special equipment that cost very expensive. The absence of equipment is a major trigger for the ineffectiveness of photoelectric effect experiments on physics learning in different universities. One alternative solution that can be used to overcome these problems is through computer simulation-based experiments. One of the familiar photoelectric simulations is the PhET simulation which can be downloaded via the URL phet.colorado.edu. Teachers should understand the concepts of physics contained in the simulation and then can develop an experimental worksheet according to the design of the laboratory activity, the PhET simulation plays a substitute for the required real equipment. The results show that the use of virtual experiments can improve students’ conceptual understanding [10,11,12]. The effectiveness of the use of virtual labs in enhancing students’ conceptual understanding is as good as the hands-on lab activity [13,14]. In fact some research indicates that students’ physics learning outcomes using virtual labs are better than hands-on lab [15,16].
3. Method
The development of HOT-VLab model is done using research and development method with ADDIE model (analysis, design, development, implementation, evaluation) [17]. The stages of the research include need assessment and reference studies, establish the instructional objectives, develop the HOT-VLab model in the form of model syntax and photoelectric effect experiment worksheet, validity test, HOT-VLab model implementation on physics experiments, and evaluation.

The HOT-VLab model validation was performed using an expert review method consisting of three physics-learning experts. Expert review results serve as a reference in refining the HOT-VLab model through revision process. Furthermore, the HOT-VLab model was implemented to 35 pre-service physics teachers (male 9 and female 26, age range 19-22 years) at a university in Bengkulu, Indonesia, in the even semester of 2017-2018 academic year. Subjects in the implementation of HOT-VLab model have studied the concept of photoelectric effect in previous lesson. The CPS and CPSS tests were performed both before and after the HOT-VLab model implementation to determine the CPS and CPSS enhancement obtained by the students. The pretest and posttest scores were used to determine the difference and increase of students’ scores from both types of tests.

4. Result and discussion

4.1. The development of HOT-VLab model
The development of HOT-VLab model starts from the analysis stage, contains the main activities in the form of need assessment and reference studies. Based on the results of the study, it can be seen that (a) photoelectric effect experiments have not been conducted in a physics education program at a university in Bengkulu, (b) the model of physics learning and physics experiments that have been applied have not been deliberately designed for HOTS [18,19], (c) obtained two models of laboratory activity which will serve as a reference for the development of the HOT-VLab model syntax. The models are PSL [7] and HOT-Lab [8], (d) there are aspects of critical thinking and creative problem solving that will be used as a reference in developing experimental activities at each stage of the HOT-VLab model. Aspects of CTS used are reasoning, hypothesis testing, argument analysis, likelihood and certainty analysis, and problem-solving and decision making [20]. While the aspects of CPSS used are explore the vision, data gathering, formulate challenges, explore ideas, and formulate and implement a plan [21].

In the design stage, the syntax of the HOT-VLab model is obtained. The HOT-VLab model design consists of a pre-laboratory phase that must be performed before laboratory activity begins and a phase of laboratory activity is performed during a laboratory activity session. The pre-lab phase consists of preparatory steps, problem description, problem formulation, pre-prediction questions, group predictions, and the determination and selection of ideas. The lab activity phase consists of exploration stage (equipment function, procedure, data collection, and data analysis), explanation stage, and conclusion stage.

In the development stage, the HOT-VLab model design is realized into the HOT-VLab model product represented in the form of a photoelectric effect experiment worksheet. The activities undertaken at each stage of the HOT-VLab model are described as follows. The preparation stage contains information on what activities to perform or what competencies a student should have before performing the experiment. The context of the problem contains a description of contextual problems that will lead to investigative activities, at the end of the problem description given some ideas that can guide students in obtaining solutions to the problems encountered. The phase of the problem formulation contains the experimental focus information to be performed and the students are asked to make the experimental statements based on the focus of the experiment. The pre-prediction question stage contains some conceptual questions that can guide students in formulating predictions. The group prediction stage contains the activity of formulating predictions. The stages of determining and selecting ideas containing activities reveal new ideas that can lead to problem solutions. If students do not have new ideas then they should be able to evaluate and select one of the ideas that have been given at the end of the problem description.
The exploration stage contains: (a) questions to explore students' understanding of the types of equipment and functions contained in the photoelectric simulation, (b) procedural questions that may lead students to the ability to formulate data collection steps (measurement and observation) which will be done. After answering all procedural questions, the students are required to prepare data collection steps and design the experimental data tables, (c) instructions for the students to make measurements and or observations following the previously prepared practice steps and organize the experimental data into the tables that have been made before, (d) questions that lead students to analyze the results of the lab data. The explanation stage contains questions that ask for explanation or evidence related to the results and experimental process that has been done. The conclusion stage contains questions that can lead students to draw conclusions based on experimental results; confirming conformity between the results obtained with the initial prediction; and recommendations for solutions to problems encountered.

The validation of the HOT-VLab model has been done through expert review by 3 physics learning experts. There are 12 aspects of assessment developed from six major aspects of HOT-VLab model worksheet construction, problem context, physics simulation used, guide questions, HOT-VLab modeling capabilities in CTS and CPSS tracing, and physical content conformity. Reviewers stated that the stages of HOT-VLab model in experimental worksheet have reflected the complete and structured phases of laboratory activity, easy to understand, and have reflected the stages of problem-solving strategies. The context of the problems used reflects real-world issues related to the concept of photoelectric effect, and able to challenge students to engage in problem-solving activities critically and creatively. Computer simulations are used in accordance with the context of the problem and the concept of photoelectric effect. The guide questions contained in each stage can lead to activities that the student should do. The laboratory activities contained in the HOT-VLab model are suitable for promoting CTS and CPSS. Some of the revised suggestions provided by reviewers include there are some guiding questions that should be summarized, there are conceptual terms that need to be fixed, and there is an image sketch that needs to be refined. Experts make the conclusion that the developed HOT-VLab model has the feasibility to be implemented in a physics experiment.

After the HOT-VLab model was revised according to reviewers' suggestions, it was subsequently implemented in a physics experiment. There are 35 students involved in the implementation of the HOT-VLab model. Three days before implementation, CT and CPS tests were tested to the students using CTS and CPSS test instrument. After that, the students are required to complete the tasks that existed in the pre-lab phase in groups. Pre-lab tasks can be done anywhere and should be collected at the next meeting before the laboratory activity phase begins. Three days later the students attended a photoelectric effect experiment using the HOT-VLab model worksheet in the physics learning laboratory. Implementation was done within 120 minutes, starting from 8 to 10 am. After implementation, posttest CTS and CPSS are performed with the same instrument as in previous pretest. The mean of CTS and CPSS pretest scores are 22.63 and 41.70, while the mean posttest CTS and CTSS scores are 63.94 and 73.04. Based on the t-test between the pre-test and post-test scores, it was found that the two scores differed significantly for both types of tests. The mean post-test score of students is significantly greater than the pre-test score. Increased scores of CTS and CTSS of students (N-gain) obtained sequentially are 0.54 and 0.53. Both N-gain scores are in the moderate category.

4.2. Discussion
The HOT-VLab model syntax represents the stages of a structured and easily understood problem solving strategy. Each stage is guided by guiding questions deliberately formulated to promote CTS and CPSS indicators. These CTS indicators are evaluate the validity of data, interpret the results of an experiment, interpret a relationship between variables, draw valid inference from given tabular or graphical information, identify the key part of an argument, infer a correct statement from a given data set, predict the probability of event, examine the relevance of the procedures in solving problems, recognize the features of problem and adjust solution plan accordingly. While the CPSS indicators used are generating and selecting multiple statements that can represent problems, generating and selecting various data/facts/information that can help understand problems encountered, generate and select...
questions that can lead to what is actually needed to solve problems, generate and choose ideas for the most appropriate to solve problems, and plan actions and apply them to solve problems.

The problem as a starting point for the HOT-VLab model laboratory activity is related to applicative technologies that can be found in everyday life regarding the physics concepts explored. In this paper, the problems used in connection with Barcode Scanner equipment that we often see at the cashier in the store or supermarket, the equipment is one of the technology development products which are based on the concept of photoelectric effect. The contextual problems given to HOT-VLab relate to issues that students may experience in their lives. The problems used in the HOT-VLab model on the concept of photoelectric effect are shown in figure 1. Characteristics of the problem will be able to provide challenges and awareness to the students to be involved in solving the problems faced. At the stage of determining and selecting ideas students are given the opportunity to express ideas that are believed to lead to problem solving solutions to be discovered through experiments. But if students feel they do not have a better idea, then they can evaluate and select one of the ideas offered at the end of the problem description. The student must provide the reason why he or she chose the idea and did not choose any other ideas, along with supporting evidence. The results of the HOT-VLab model implementation indicate that the problems used may encourage the improvement of their CTS and CPSS. This is in line with the results of previous research which states that issues that meet the elements of appropriate for students, ill structured, collaborative, authentic, promote lifelong and self-directed learning can be used to promote higher-order thinking of students [22].

During the semester break, you and some of your friends work part time in a company engaged in electronic products. Currently the company is developing Barcode Scanner device to read the barcode contained on the packaging of a product. The company wants to produce a more energy-efficient Barcode Scanner device, so the rays used to highlight barcode paper should be able to be set at medium intensity with a certain frequency. There are two important things in the Barcode Scanner, which are the characteristics of the rays used to highlight barcode paper, and metal plates inside a device that serves to receive back rays reflected by barcode paper. The reflection of light received by the metal plate will cause the emission of electrons from the metal surface in such a way that the photoelectron can generate an electric current in an electrical circuit. The resulting electrical current is then translated into specific codes to describe the specifications and prices of a product. For its metal plate, the company has decided to use a sodium (Na) material that can absorb light in the wavelength range 320 nm - 560 nm. But the company has not decided how much the visible light frequency should be used so that the resulting electric current can reach the minimum required for the coding process. The company leader asks your group to investigate and determine how much the most visible light frequency is best used to generate the minimum amount of electric current required for the coding process of 0.091 A.

As group leader, you ask the opinion of the three members of your group regarding the large frequency of light that will be used for the Barcode Scanner device to meet the desired characteristics. Their opinions are as follows:

- Jack believes that the frequency of light to be selected is the smallest frequency (equivalent \( \lambda = 560 \text{ nm} \)) with the maximum light intensity. Small frequencies will produce large wavelengths so that the resulting photoelectron energy becomes maximal. In addition, the use of large light intensity can produce a maximum electric current. Barcode scanners should use the smallest light frequency with the greatest light intensity.
- Erwin argues that the light used must have the greatest frequency (equivalent \( \lambda = 320 \text{ nm} \)) and intensity at a moderate level. Maximum light frequency will produce photoelectron with the maximum amount and speed so that it can generate large electrical current required in the coding process. The intensity of the selected light must be at a moderate level to produce an energy-efficient barcode scanner.
- Tony argues that the light used must have the greatest frequency in the visible light range (equivalent \( \lambda = 384 \text{ nm} \)) with intensity at a moderate level. The greater the frequency of light used, the number of photoelectrons emitted from the metal surface and photoelectron kinetic energy will be greater so that the electric current generated will be even greater. The intensity of light used is not necessarily the maximum so that the electrical energy used to generate the light is not great, it is intended to meet the specifications of the more energy-efficient devices.

The three members of your group have different opinions and reasons. You get confused about who to choose. To determine whose opinion is most appropriate, you can investigate through a photoelectric effect experiment using a computer simulation with the following activity stages: ...

Figure 1. Description of the problem in the HOT-VLab model on photoelectric effect concept.
In contrast to the PSL and HOT-Lab models that further highlight the physics measurements to obtain experimental data, such as measuring spring coefficients, calculating the swing period of pendulum and so on, the HOT-VLab model emphasizes the observation aspect other than measurement. Most of the students' activity is to observe microscopic symptoms that have been visualized through computer simulations. The ability of students to observe will lead them to the ability to predict, interpret, analyze, and explain. For example, in a photoelectric experiment, when the light frequency used to illuminate a photocathode is below a certain value (threshold frequency) the photoelectron will not be generated (students will not observe electrons detached from the material) despite the maximum intensity of light. In contrast, a photoelectron will be generated (students may observe the presence of electrons emitted from the surface of the material) when the frequency of the rays used is greater than or equal to the threshold frequency even when the light intensity is small. The results of this observation will lead students to an analysis that photoelectron energy is only influenced by the frequency of light photons and not at their intensity as classical physics assumes. In addition, the results of these observations will lead to students' ability to predict the magnitude of the threshold or work function of a metal material.

The HOT-VLab model has an explanatory stage that is not found in the PSL or HOT Lab models. At this stage students are asked to answer questions that demand an explanation of the results and the experimental process. Explanation is believed to be one of the techniques that can be used to train students to HOTS [2]. Students can provide further explanation of what they have found or experienced directly by providing supporting evidence.

The results of the HOT-VLab model implementation provide evidence that this model can be used to improve student CTS and CPSS. This model does not require additional time consumption beyond the set time target in each experiment activity. The implementation results also provide assertion that HOTS students can be improved through problem-solving learning environments enriched with computer technology [1]. The developed HOT-VLab model can serve as an alternative solution for the absence of advanced laboratory equipment in the laboratory. The HOT-VLab model can also be applied to other abstract concepts to promote and train higher-order thinking skills.

5. Conclusion
The HOT-VLab model that has been developed has the ability to improve students’ CTS and CPSS on the concept of photoelectric effect. The HOT-VLab model is represented through an experimental worksheet consisting of preparation stage, problem description, problem formulation, prediction question, group prediction, determination and selection of ideas, exploration (equipment, procedures, data collection, data analysis), explanations, and conclusions. Student activities at each stage are guided by guiding questions deliberately designed to promote aspects of CTS and CPSS. The HOT-VLab model can serve as a model of laboratory activity that can provide higher-order thinking skills through physics experiments involving abstract and microscopic concepts.

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