Assessing pre-service physics teachers’ competencies in designing photo-electric effect experiment using PhET simulation

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Abstract. The advancement of learning technology requires that pre-service physics teachers should have adequate skills to integrate technology in the teaching and learning process. This study aimed to investigate the competencies of prospective physics teacher of Jambi University in designing the photo-electric effect experiment. This study used a mixed method approach with exploratory models. Ninety physics education students of Jambi university, having taken modern physics subject, were participated. Data were obtained from the students’ work of designing photo-electric effect experiment using PhET simulation. The students were asked to work in group, but the final report was done individually. Data analysis were done based on indicators of competencies to design a virtual lab activity. The indicators consisted of abilities to declare the objectives of experiment, compile the theoretical basis, and set up the procedure. The findings showed that the average ability of the prospective physics teacher in designing photo-electric experiment using PhET simulation was in the low category. Based on interviews, it was due to aspects of unfamiliarity with PhET simulation, technical problems related java player installation, insufficient of prior knowledge, and lack of skills in finding relevant information.

1. Introduction

Teaching and learning that mainly focus on reading texts and formulas will cause difficulties for students to understand many complex phenomena in physics. College students do not ordinarily think that it is hard to utilize arithmetic and formulae, which is not astonishing thinking about that their guidance centres around these segments [1]. Conventional guidance in material science courses concentrated on critical thinking disregards significant procedural objectives and is typically concerned for the most part with numerical activities [2]. This Traditional approaches for the most part prompt poor accomplishment as far as creating abilities and strategies related with critical thinking [3]. Analysing the impact of using simulation-based materials, it was found that the number of the experimental students who used expert-type scientific procedures consisting of qualitative analysis of the problem, making hypotheses, and analysis of results were increased and there was a decrease for the number of those whose habits based solely on mathematical equations [4].

In the curriculum which based on the scientific approach, practicum becomes an essential method that can not be separated from physics teaching and learning paradigm. With practical lab activities, students will have more opportunities to think and experience like physicists which construct their
Physical knowledge through observing and conducting experiments, collecting data, analyzing data, interpreting and communicating the phenomena they get from experimental results [23]. Learning through practicum is also a type of group learning. In various research studies proving that working in a group has a very important role in addition to obtaining effective results and good understanding [11][24]. Furthermore, learning through practicum at this time is not limited in the real laboratory, but can also be done with virtual-lab media.

Virtual laboratories can replace physical laboratory equipment and as learning assistance that can help students understand concepts and unify knowledge [13]. Virtual laboratories can be a supporter in developing and changing conceptual understanding of physical phenomena in various spheres of physics science [20]. The use of computer simulations is a solution to the absence or limitations of practicum tools and learning media due to facilities and funding factors [30]. Virtual laboratories can support the acquisition of conceptual knowledge [28], namely that reality can be adjusted to serve the learning process [27]. In addition, in science education, especially physics, it has been considered that this ability has been very important since the 19th century [12]. Virtual laboratories provide the opportunity for users to conduct investigations and experiments that associate with experimental objects based on the user's skill level [16]. Virtual laboratories can stimulate active involvement with material, and expose students to gain limited external experience in the classroom [29]. Virtual laboratories offer quick access to experiments [17], whereas in physical laboratories a lot of time is often needed to prepare equipment, and experiments cannot be repeated quickly, and in a virtual laboratory can do dangerous experiments without endangering ourselves or others and can be used without additional costs as much what we want [14].

As technology advancements have shown an incredible potential to improve teaching and learning, this century physics students, as future and prospective physics teachers, are expected to have adequate skills to incorporate ICT-based media in the classroom and lab activities. Teachers must be familiar with a variety of pedagogical approaches and appropriate ways of using ICTs to support the skills of their twenty-first century students. The framework of technology pedagogical content knowledge (TPACK) provides a theoretical model for examining how teachers use ICT in education [26]. In addition, teachers have to prepare to gain high quality of competency in integrating technologies into teaching practice [31]. The measurement of the TPACK ability of pre-service physics teachers is very important to be done continuously to find out its current impacts dan advances.

As there is still a few studies in the measurement of the TPACK ability of pre-service physics teachers T in designing the photo-electric experiment using PhET simulation, this paper’s objectives are:

1. To measure the TPACK competencies level of physics education students of Jambi University in designing photo-electric experiment using PhET simulation.
2. To find out the problems faced by the students in designing photo-electric experiment using PhET simulation.

In this study, the indicator of TPACK competencies are adapted from TPACK indicators in the domain of point 5: advancing [33].

2. Literature Review
PhET is a web-based simulation project at the University of Colorado that develops a simulation tool focused on science education including physics. This simulation is a physical simulation model that is accurate, visual, and has dynamic representation of physics principles [13]. PhET simulation uses a research-based approach that combines previous findings and self-testing to create simulations that support student involvement and understanding physics concepts [25]. There are several learning settings provided in PhET, including lecturer, individual or small group activities, home assignments and laboratories [27]. This setting is specifically designed to support students in building strong conceptual understanding of physics through exploration and analyzing the results of problem-solving activities [6]. This simulation helps students in building daily understanding with the underlying
concepts, for example the existence of physical models such as electric currents and magnetic fields that cannot be demonstrated in a physical laboratory in the form of microscopic scale [13].

Integration of ICT tools in classroom setting is an ability to connect 3 essential aspect about teaching skills: content, pedagogical, and technological knowledge in order to enhance teaching and learning process. This modern teacher skill called TPACK competency was firstly proposed by Mishra and Koehler in 2006 [31]. An assessment study focused on the ability in using a computer simulation media of pre-service teachers. The results showed that there was a significant improvement on their post-test scores. In contrast, another study found that the simulation caused problems to the group’s exploration process. The group was more effective and productive in the physical situation than in the simulation. Nevertheless, these conclusions may be definite to the particular simulations used. In addition, the students’ degree of acquaintance with the ICT tool also need to be considered. The investigators stated that the group had difficulties understanding the simulation, resisted to practice it successfully, and the students did not take full benefit of the ICT tool’s features [32].

In the domain of content knowledge physics education students have to master the following equations which governs the photo electric effects to occur [34]:

**Light energy:**
\[
E = \frac{nhf}{\lambda}
\]  

(1)

The binding energy of metals (work function):
\[
\phi = hf_0
\]  

(2)

Energy of the electrons released:
\[
E = E_k = eVs
\]  

(3)

Photoelectric effect equation:
\[
hf = hf_0 + E_k
\]  

(4)

Beside understanding mathematical equations, knowing well the theory and its empirical measurement results. The classical physics theory expects that the properties of the emitted photo-electrons:

1. As the intensity of the light source is enlarged, more energy is carried to the surface (the electric field is greater) and the electrons should be released with greater kinetic energies. In the same way, increasing the intensity of the light source rises the electric field E of the wave, which also increases the force \( F = -eE \) on the electron and its kinetic energy when it eventually releases. The intensity of the radiation should be linear to the kinetic energy of the electrons.

2. Based on the wave theory, as long as the radiation is intense enough to release electrons, the photo-electric effect should befall independent with the frequency of the light. The photo-electric effect should happen for light radiation of any frequency or wavelength.

3. In the wave theory, the energy of the wave is uniformly distributed over the wave front as a result the first electron should be discharged in a period of the order of seconds after the light strike the metal’s surface.

The experimental results which suggest the complete failure of the wave theory to account for the photo-electric effect [34] :

1. For a fixed value of the wavelength or frequency of the light source, the maximum kinetic energy of the emitted photo-electrons (determined from the stopping potential) is totally independent of the intensity of the light source.

2. Doubling the intensity of the source leaves the stopping potential unchanged, indicating no change in the maximum kinetic energy of the electrons. This experimental result disagrees with the wave theory, which predicts that the maximum kinetic energy should depend on the intensity of the light.

3. The photo-electric effect does not arise at all if the frequency of the light source is below a certain value. This value is called the cut-off frequency \( f_c \). Below \( f_c \), no light source, no matter how strong, will cause the emission of photoelectrons and above \( f_c \), any light source, no matter how weak, will cause the emission of photoelectrons.
4. There is not a time delay, the first photo-electrons are emitted virtually immediately (within 10–9s) after the light source is turned on. The wave theory predicts a measurable time delay, so this result also disagrees with the wave theory.

3. Research method
The research uses a mixed method approach with the exploratory model which is designed to collect, analyze and incorporate quantitative and qualitative methods [8]. The research subjects were 90 students of the Jambi University physics education who have taken modern physics courses in which the phenomenon of photo-electric effects was studied. Students were grouped into groups, each group consisting of 3-4 students. Each group of students was asked to design experiment based on PhET interactive simulations on photo-electric effect by conducting observation, finding related references/resources and working to set up the experiment. Data were taken from the final reports done collaboratively by students in a group but finished and reported individually. To assess the ability of students to design this lab activity, an assessment instrument has been developed as listed in Table 1. The criteria used in this assessment is derived from TPACK indicators in the domain of point 5: advancing which consists of [33]:

1. Technology-based activities include inquiry tasks of high cognitive demand.
2. Technology procedures concentrate on mathematical or scientific tasks with connections and doing mathematics or science – and on inquiry activities that use or develop deep mathematical or scientific knowledge representing connections and strategic knowledge.

Furthermore, selected students were interviewed for the purpose of confirming the results and the problems that students face during the task completion. Data were analyzed quantitatively and qualitatively to acquire information about the ability of prospective teachers to design a virtual lab activity. Qualitative data from interviews are analyzed by reducing and classifying techniques to look for the valuable information regarding the obtained quantitative data [21].

Table 1. Indicators of competencies in designing photo-electric experiment using PhET simulation

| Competency | Indicator | Rubric |
|------------|-----------|--------|
| A. Declaring the objective of the experiment | A1. Objective 1: to investigate the effect of light intensity on current. A2. Objective 2: to investigate the effect of light wavelength on current. A3. Objective 3: to investigate the effect of light intensity on electron energy. A4. Objective 4: to investigate the effect of light wavelength on electron energy. A5. Objective 5: to measure the stopping voltage and electron energy A6. Objective 6: to determine the work function of metal A7. Objective 7: to determine the Planck’s constant h | Declaring the objectives according to the listed indicators (each point score=5) |
| B. Providing the theoretical foundation | B1. Appropriate B2. Systematic | Using equation from (1) to (4) Presenting the equations in |
B3. Using relevant resources
Using references from book or journal
(each point score=10)

C. Setting up procedures
C1. Appropriate based on the concept
Setting up procedures according to the objectives
Using PhET features appropriately

C2. Appropriate based on PhET features

C3. Systematic
Writing procedures in the right logical order
(each point score=10)

4. Result and Discussions
In the phase of observing PhET simulation, students are given the opportunity to try, observe and be familiar with the function of each part of the tools. This is done individually and collaboratively in each group which is very important so that students as prospective teachers have skills in collaborative learning.

The quantitative results showed that the average students’ TPACK competency score is low (40.33). This level of competency comprises of declaring experimental objectives 37, writing a theoretical foundation 46, setting the procedure 38. In term of percentage, among these prospective physics teachers, it is found that 46% were categorized as low (<50), and 48% as intermediate (50-70), and only 6% achieved high competencies (> 70).

![Scores of competencies](image)

**Figure 1.** Score of 90 student’s abilities to design photo-electric experiment using PhET simulation

These results reveal that even though students have studied the concept of photo-electric effects in modern physics courses, they still do not have enough competency to apply the concept in the experiment context. In addition, the habit of students who are more inclined to manipulate equipments but not improve ideas is one of the factors of the low achievement in the ability of physics education students to design a good experiment as part of creating teaching plan skills [12].

Formulating the objective of the experiment is one indicator that must be met by physics education students in designing lab activities. In formulating the experimental objectives, students did it based on their experience in studying the theory of the electric photo effect. If students are familiar with the active student learning approach, they will be able to design this experiment without relying on teacher explanations. This is in accordance with what explained by the authors: when the role of students in investigating, thinking, planning exercises, and reflecting is very emphasized, or all learning is student-centered, open questions must be used as learning approaches [22]. Based on the research data
in Figure 1, it shows that the average score of students' abilities to formulate the objectives of the experiment is 39. With the lowest score of 25 and the highest 83. These results reveal that students still do not understand the experiments that will be conducted on photoelectric effect topic. One of the basic causes of the inability of students to state the goal of the experiment is the weak understanding of students on concepts regarding the theory of photo-electric effects in the subjects of modern physics they have studied. This finding is supported by the statement that for prospective teacher students, the lack of understanding of content or theory is a challenge in a practicum [18].

Students are said to search and use the appropriate theoretical foundation when it is used to support the design of the experiments conducted. It is because, relevant sources are one of the important factors that affect their success in this design task. Based on Figure 1, the average score of student's abilities to search and use the correct and appropriate theoretical foundation is also low, 48. From the sample of interviews:

Student 1 : "...... I didn’t find, on the PhET web, the materials or samples of conducting the experiment using PhET simulation"

Student 2 : "...... I only find the samples of this experiment from the blog not from journal “

Student 2 : "...... I have difficulty in understanding the samples of the experiment as it is in English"

These results indicate that some students have a lack skill in searching relevant sources on the Internet as learning references. Some students still rely on irrelevant internet information whose sources do not have a high validity. The use of sources that are less valid as references is confirmed by interview. It is noticed that, some groups still use theoretical sources from blogs and other unwell known websites. These results show that students are still exposed to the habit of using a low quality of references. However, there are also some students who have tried to get relevant sources from books and journals. Nowadays, Since the relevant materials are so numerous, a selection must be made [15]. Understanding the concept from relevant references will determine the success of students to set up the experiment and collect the appropriate data. In addition, the difficulties are also caused by unfamiliarity in reading English materials.

Students' understanding of modern physics as the prerequisite course, and the use of the correct theoretical basis have a remarkably close link to the ability of students to design experimental procedures. This is because, if students understand the concept and the theory correctly, they will find that it is not too difficult to design the experiment procedure. Moreover, the ability to design experimental procedures without the full help of their lecturers is in line with a student-centered view which is the best approach in modern teaching [19]. Based on Figure 1, the average score of competencies of students to design experiment procedures is still in a very low category with an average value of 40. These results illustrate several things, i.e. most students do not adequately understand its prerequisite course: modern physics, especially the concept of photo-electric effects. In addition, in making a theoretical foundation, students do not try to re-learn the previous related course.

The most interesting thing from the students' design results in setting up experimental procedures is about the parameter of determination that some students proposed. They argued whether the electrons have been released from the metal is based on seeing the electrons released from the metal’s surface or on reading the amperemeter. The reason is that released electrons will be visible to the eye even though only one electron is released. If the determination of the released electrons is by seeing microscopically then 1 released electron is enough to conclude that the incoming light energy is exactly the same as the metal working function. In contrast to experiments in real labs, the released electrons cannot be seen, and only can be measured by means of which have a limitation of sensitivity. This means that there must be a certain number of electrons released so that the amperemeter can read it and it may not be enough if only one electron. This a good critical thinking is the result of using
A computer simulation that can visualize photo-electric effect in microscopic scale, and it is one of evident that using ICT-based media increases the students’ critical thinking. A case study, has been conducted by Salleh et al., investigated the impact of the web-based simulations on the critical thinking skills of 21 university students. The finding is that a positive impact on students’ critical thinking skills was measured after the implementation of web-based simulation learning framework [35].

![Figure 2. The definition of the released electron based on directly seeing the electrons (left) and reading the amperemeter (right)](image)

It can be seen from Figure 2 that there are more than one electron released even though the amperemeter read it as zero current. In this simulation tool, the amperemeter will display non-zero current if the intensity is greater than 10%.

Regarding the students who have low scores, the cause that affect students' ability in setting up the experiment using PhET is their inability to appropriately use PhET simulation. This is supported by the results of the interviews:

**Student 1**: "...... we do not understand how to use the PhET simulation on electrical photo effects practices"

**Student 2**: "Constraints at the time of observation, and still not understanding doing practicum using PhET"

**Student 3**: "The problem is when observing the tool, I don't understand what should be practiced on the concept of photo-electric effects ...

**Student 4**: ""PhET didn’t work in many of our laptop..."

The student 1 try to explain that he/she has the concept-related problems while student 2 has technical problems with the fact that PhET is java-platform which cannot be run directly, and it needs specific installation procedure. Java-based simulation often has problem of not working in many students’ laptop. In addition to java platform having many advantages, this platform is vulnerable to cyber-attacks and is no longer compatible with secure browsers. Recently, many web-based simulations are moving to HTML5 framework [10]. These findings suggest that HTML-based simulation is the future best of simulation platform for reducing technical problems faced by the users.

The interview reveals that the students' inferior score of competencies to set up experiments using PhET simulation might have a relation to student habits outside of the classroom that influent students' ability to incorporate technology in teaching and learning plan. This was stated that “Our position is transformative in nature because it proposes the use of cyber-enabled resources for cultivating and leveraging student’s new literacy skills by learning ‘with technology’ to enhance science learning” [5].
The explanation might be that changing the understudies' directions towards learning material science needs lengthy timespan that the students concentrate the greater part of their physics science courses utilizing the conventional technique that do not assist them with having uplifting perspectives towards learning physics science using computer simulation [9]. In addition, familiarity in dealing with such virtual-lab simulation also needs to be take into account [33]. A research focused on the review of the related literature, it found that self-efficacy affects the use of ICT tools in their teaching and learning process. It is the judgment of one’s competence to adopt and use a technology. It mentioned that one’s use of technology was determined by self-efficacy factor and that people who had higher self-efficacy beliefs will use technology more intense than those who had less self-efficacy beliefs [12].

5. Conclusion
The prospective physics teachers in this century really in need of being able to incorporate ICT tools in their teaching and learning especially PhET simulation which is widely available and free. The 3 abilities consist of formulating the objectives, compiling the theoretical basis and setting up procedures have been used to assess the TPACK competency of pre-service physics teachers in designing an experiment. The results show that the average score of ICT competency of physics students of Jambi University dealing with virtual simulation usage is still in the low category. This is mainly due to problems of unfamiliarity with PhET simulations, technical problems related java player installation, insufficient of prior knowledge, and lack of skills in finding relevant information. These findings also suggest that HTML-based simulation is a better platform of simulation media for reducing technical problems faced by the users. Investigation of appropriate approach to improve the ability of students to design teaching plan using such virtual simulation needs to be further explored.

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