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Development and Students' Perception on Teaching Aids of Photoelectric Effect Experiment Using Leds

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Abstract – *The photoelectric effect experiment generally uses a very sophisticated and expensive apparatus. Some high schools and even universities in Indonesia cannot afford to conduct this experiment because of the high price of the apparatus. The purpose of this study was to develop a user-friendly, and cost-effective teaching aids which can be used to demonstrate the concepts of modern physics related to the photoelectric effect. The stages of this study employed the Four-D model, namely define, design, develop, and disseminate. Based on experts and practitioner evaluation, the developed teaching aids and practicum devices of photoelectric effect experiment were found to be valid and reliable. The results of the experiment by using this developed teaching aids of the photoelectric effect showed that there is a linear relationship between the stopping potential and the frequency of light emitted by the LED. These results are consistent with Millikan's experimental results, the first physicist who succeed in proving Einstein's hypothesis of the photoelectric effect, that in the photoelectric effect the stopping potential does not depend on the intensity of light but depends only on the frequency of light. In this study, the Planck's constant value obtained is* $6.408 x 10^{-34}$ *J.s. Although this value is slightly smaller than the accepted value of Planck's constant that is* $6.626 x 10^{-34}$ *J.s, it is good enough considering the instrumental error occurred during the measurement of current and voltage. Furthermore, the students' perception of the developed teaching aids and practicum devices of the photoelectric effects experiment are 74.9% (good) and 80.2% (very good), respectively. This indicates that the photoelectric effect experiment teaching aids and practicum devices that have been developed can be used to demonstrate and prove the concepts of modern physics related to the photoelectric phenomena correctly.*

Keywords: *Teaching Aids, Photoelectric Effect, Students' Perception*

I. INTRODUCTION

Experiments have a central role in the development of physics. Even almost all literature mention that physics is an experimental science. This is not surprising given that experiments appear as a central scientific tool. Richard Feynman, one of the leading theoretical physicists of the 20th century, said that experimentation is a tool for testing all scientific knowledge and it becomes the sole judge of scientific truth (Feynman et al., 1963).

Both real experiment and thought experiment play an important role in building scientific theories. Many physicists use these two experiments to construct new theories, confirm the hypotheses or refute existing theories (Brown, 1986; Reiner, 1998; Cooper, 2005). In the field of physics education, several studies have been focusing on the role of these two types of experiments in physics

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teaching and learning. For example, the reconstruction of experimental epistemology and the classification of experiments based on the objectives of teaching physics in schools had been done to prevent physics teachers from using inappropriate experiments (Koponen & Mäntylä, 2006; Etkina et al., 2010). In Indonesia, particularly, science experiments skills of pre-service and in-service physics teachers have been analyzed by several researchers (Hamdiyati & Kusnadi, 2007; Bancong & Putra, 2017; Hamdani, 2017) who concluded that the majority of pre-service and in-service physics teachers have difficulties in building hypotheses, classifying related variables, and predicting the results when conducting experiments. The Indonesian physics textbooks for high school students have also recently been analyzed and evaluated by Bancong & Song (2018) to see whether thought experiments presented in the textbooks can be used as a tool to teach scientific knowledge. All of these concerts shows that experimentation seems to be important especially in the teaching and learning of physics.

The experiment of the photoelectric effect has been widely described in modern physics textbooks. It has been around 97 years since Albert Einstein was awarded the Nobel Prize for his explanation of the photoelectric effect. This explanation is the core of our understanding of light as a particle. Generally, the classic tools used to demonstrate this experiment will include phototubes, voltage sources, amperemeters, voltmeters, and light sources which can produce some narrow light bandwidths, such as mercury lamps or incandescent lamps.

However, the classic apparatus of the photoelectric effect experiment are very sophisticated and more expensive. Some high schools and even universities in Indonesia cannot perform this experiment because of the high price of the apparatus. Therefore, the purpose of this study was to develop affordable photoelectric effect experiment teaching aids which can demonstrate the physics concepts related to photoelectric effect. We also developed the practicum devices as a practical guide in using this photoelectric effect experiment teaching aids that have been developed. Therefore, the research questions in our study were:

1) Are the developed teaching aids and physics practicum devices of photoelectric effect experiment valid and reliable?
2) What is the students' perception of the photoelectric effect experiment teaching aids and the physics practicum devices that have been developed?

II. METHODS

This is a development research using Four-D model which includes define, design, develop, and disseminate (Thiagarajan et al., 1974). However, the dissemination stage was

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not carried out due to time constraints. Restricted trials of the use of teaching aids and practicum devices that have been developed are carried out at State University of Makassar and Muhammadiyah University of Makassar.

The *define phase* aims at determining and defining the requirements for the development of teaching aids which consist of problem analysis, students analysis, and concept or material analysis. Meanwhile, the purpose of the *design phase* is to prepare prototypes of photoelectric effect experiment teaching aids and practicum devices. Then, the *develop phase* aims to obtain photoelectric effect experiment teaching aids and practicum devices which are valid and reliable.

Validation data from experts and practitioner were analyzed by calculating the CVR (Content Validity Ratio) and CVI (Content Validity Index) according to the following equation. If the CVR and CVI values are in the range of 0 to 1, the statement is said to be valid (Lawshe, 1975).

$$CVR = \frac{n_e - \frac{N}{2}}{\frac{N}{2}}$$

$$CVI = \frac{CVR}{\Sigma n}$$

n_e: Number of validators that provide essential values (good or very good)

N: Number of validators.

Furthermore, reliability analysis was carried out if all statements are valid. The calculated reliability value was compared to the reliability of table value. If the count reliability value is higher than the table reliability value, then all statements are said to be reliable.

III. RESULTS AND DISCUSSION

Define Phase

Based on the problem analysis, the teaching aids of the photoelectric effect experiment was decided to be designed and developed in this study. The photoelectric effect is one of the experiments that underlie the development of modern physics, especially quantum theory. The development of radiation theory underwent a major change when Max Planck was able to provide a formulation that contained all data of blackbody radiation perfectly (Planck, 1901). Like Planck, Einstein also formulated the distribution of blackbody radiation by analyzing the entropy of blackbody radiation. This allowed Einstein to state that at high frequencies, blackbody radiation behaves like a gas quanta where every quantum of radiation (at frequency *v*) has energy *h.v* (Einstein, 1905). He then proposed to quantify this radiation by the properties of the photoelectric effect.

Design Phase

The user-friendly, cost-effective, and reliable design of the photoelectric effect experiment teaching aids can be seen in Figure 1. The principle of this experimental apparatus is that an amount of current will

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flow from the voltage source to the resistor and the light emitting diode (LED). The LED is a semiconductor device that behaves as a bulb lighting up when connected to a voltage generator. The LED emits light only when the voltage is forwarded and above a minimum threshold value (Garver, 2006; Checchetti & Fantini, 2015). Therefore, by measuring the voltage at which the LED turns on, we can determine the energy of the emitted photons ($e.Vt$). Also, by using LEDs of different colors (different frequency), we can find that the energy of photons varies depending on the frequency of light emitted by the LED. In addition, by using the ratio of energy photons ($e.Vt \approx h.v$), h (Planck's constant) can be determined. The Planck's constant value can also be calculated by plotting V_t (stopping potential) vs. v (frequency) and determining the slope of a straight trendline fitting of the data.

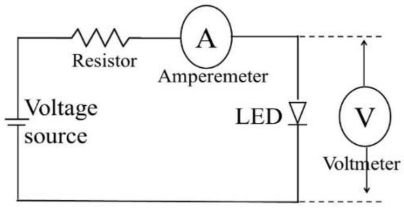

Fig. 1. Design of the photoelectric effect experiment teaching aids

Develop Phase

The results of the validation by experts and practitioner can be seen in Table 1. As shown, the average CVI value for all categories is 1. This is because all validators provide essential values (good and very good), so CVR for all items in each validation aspect is 1. CVI value is obtained from the number of CVR values divided by the number of items in each validation aspect. Because the CVI value obtained is equal to 1, teaching aids, practicum devices, and instrument of students' perceptions were declared valid.

Table 1. The result of the validation

Category	Validation Aspect	Average Percentage (%)				Criteria
		Validator 1	Validator 2	Validator 3	Average	
Teaching Aids	Material	82.14	78.57	85.71	82.14	Very Good
	Practical Practices	79.17	79.17	83.33	80.56	Very Good
	CVI				1	Valid
	Reliability				0.99	Reliable
Practicum Devices	Format	80.00	85.00	75.00	80.00	Good
	Content	90.00	80.00	80.00	83.33	Very Good
	Language	81.25	87.50	75.00	81.25	Very Good
	Physical Display	75.00	83.33	75.00	77.78	Good
	CVI				1	Valid
	Reliability				0.99	Reliable
Perception Instruments	Instruction	100.00	87.50	75.00	87.50	Very Good
	Language	81.25	81.25	81.25	81.25	Very Good
	Content	87.50	75.00	75.00	79.17	Good
	CVI				1	Valid
	Reliability				0.99	Reliable

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Furthermore, the reliability value (R_{count}) for the teaching aids category (total statements = 13) is 0.998. When compared to the reliability table (R_{tabel}) for n = 13, 0.5324 (5%) and 0.6614 (1%), it is obtained that R_{count} is greater than R_{tabel} (0.998 > 0.6614 > 0.5324). Therefore, the teaching aids that have been developed was declared reliable according to the judgment of experts and practitioner. Likewise, for the practicum devices category (n = 17) and the students' perception instrument (n = 17), it is obtained that R_{count} value (0.998) is greater than R_{tabel} for 5% and 1% error rates. Hence, it can be concluded that the overall teaching aids, practicum devices, and instrument of students' perceptions that have been developed were declared valid and reliable according to the judgment of experts and practitioner.

Tryout

The experimental data by using the developed teaching aids of the photoelectric effect experiment can be seen in Table 2. As shown, there is a linear relationship between the stopping potential and the wavelength of the light emitted by the LED. In other words, the stopping potential varies linearly with the frequency of light. These results are consistent with Millikan's experimental results, the first physicist who succeed in proving Einstein's hypothesis, that the stopping potential depends only on the frequency of light in the photoelectric effect. Also, the frequency of light is directly proportional to the photon energy (Millikan, 1916).

Table 2. Measurement results of the stopping potential for several different LEDs

LED	λ (nm)	f (Hz)	V_t (Volt)	E (Joule)
Red	631	$4.75x10^{14}$	1.8	$2.88x10^{-19}$
Yellow	593	$5.06\ x10^{14}$	2.1	$3.36\ x10^{-19}$
Green	525	$5.71\ x10^{14}$	2.4	$3.85\ x10^{-19}$

The value of Planck's constant is analyzed by plotting the graph of the relationship between the frequency of light emitted by the LED and the stopping potential (Figure 2). The slope of the line (*h/e*) is $4x10^{-15}$. If this value is multiplied by the electron charge, e = $1.602x10^{-19}$ C, then the value of Planck's constant is measured to be $6.408x10^{-34}$ J.s. The error percentage represents the 5 % uncertainty when measuring the current and voltage during experiment.

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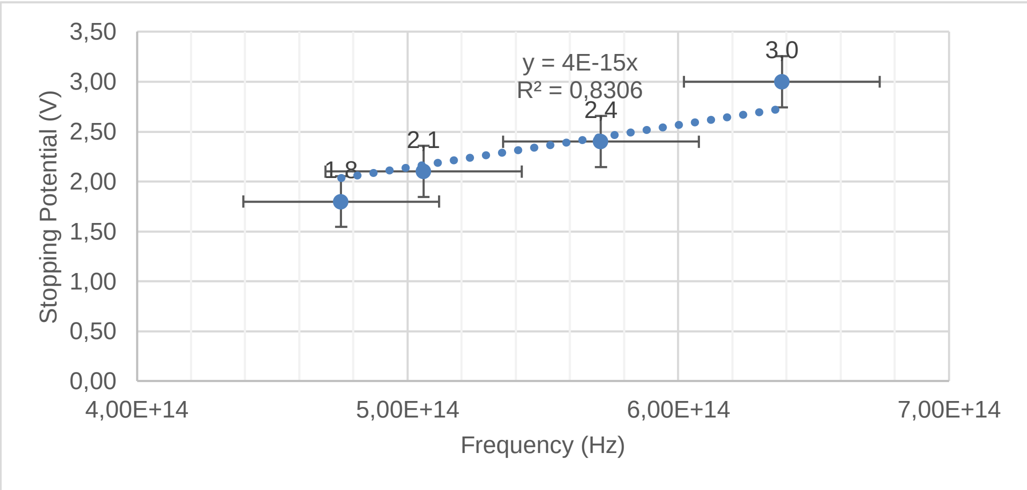

Fig. 2. Stopping potential as a function of the LEDs frequency

Students' perception (n = 30) is measured after they used the developed teaching aids and practicum devices. Students were given questionnaires consisting of 20 questions which referred to the perception of the teaching aids and practicum devices. The average students' perception towards teaching aids and practicum devices is 74.9% (good) and 80.2% (very good), respectively. For each indicator of the perception, the percentage is presented in a bar diagram as shown in Figure 3.

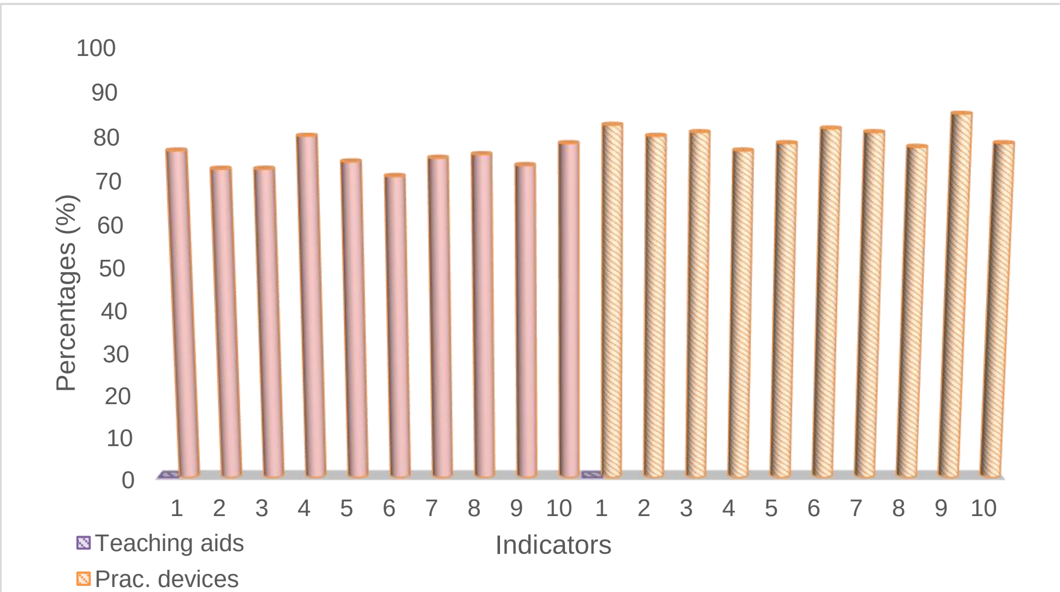

Fig. 3. The percentage of students' perception of the developed teaching aids and practicum devices.

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In this study, the researchers describe a user-friendly, and cost-effective apparatus that can be used anywhere to demonstrate the photoelectric effect experiment using LEDs. It should be noted that this method (measuring the photon energy when LEDs turn on) is slightly different from some studies that also use LEDs to demonstrate the photoelectric effect. For example, using LEDs as light source to illuminate the photocathode (Garver, 2006; Loparco et al., 2017), using a small neon bulb and white LED together (Cortel, 2006), or measuring the Planck constant by deriving the voltage-current characteristic curve for a series of different color LEDs (Checchetti & Fantini, 2015)

At present, the measurement of Planck's constant is usually done by several methods. The most common method is to utilize the experiment of blackbody radiation (Dryzek & Ruebenbauer, 1992; Brizuela & Juan, 1996), or photoelectric effects (Millikan, 1916; Keesing, 1981). However, the equipment of these methods are rather complicated and more expensive. Therefore, this study offers different ways to measure Planck's constant with the measurement of the energy of the photons emitted by the LEDs. The Planck's constant value obtained is slightly smaller than the accepted value of Planck's constant of 6.626×10^{-34} J.s. However, it is good enough considering the instrumental error occurred during the measurement of current and voltage. Therefore, in general it can be said that the teaching aids and practicum devices of the photoelectric effect experiment that have been developed can be used to demonstrate and prove the concepts of modern physics related to the photoelectric phenomena.

For physics education, the laboratory has become a hallmark. The purpose of laboratory activities is not only to demonstrate physics concepts, but the most important things are to achieve the students' maturity and autonomy in thinking, and to increase the capacity of collaboration among them. Lack of information about the best professional practices, and inadequate laboratory equipment, including syllabus preparation for physics laboratory will influence the students' perceptions and their behavior in the laboratory (Hofstein & Lunetta, 2004; Hırça, 2013). Therefore, it is important to find out the students' perceptions of the developed teaching aids and practicum devices to know students' responses. Through response analysis, some critical points will be available for future improvements.

Laboratory activities also provide the possibility to lead students to teamwork. The teachers must be careful of the dynamics in the group consisting of several students who do not know each other before. Teachers must also learn how to organize and utilize different skills from each group member because they have different thinking styles and multiple intelligence (Bancong & Subaer,

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2013; Safitri et al., 2013). Therefore, the collaborative members who have different thinking styles in a group will make students enjoy doing teamwork so that that laboratory activities will be fun for all students.

IV. CONCLUSION

We have designed and developed a user-friendly, and cost-effective teaching aids and practicum devices of photoelectric effect experiment. Based on experts and practitioner evaluation, the developed teaching aids and practicum devices of photoelectric effect experiment were found to be valid and reliable. The results of the experiment by using this developed teaching aids are consistent with Millikan's experimental results, the first physicist who succeed in proving Einstein's hypothesis, that there is a linear relationship between the stopping potential and the frequency of light. Therefore, this teaching aids and practicum devices can be used to demonstrate and prove the concepts of modern physics related to the photoelectric phenomena correctly. Students' perceptions of this developed teaching aids and practicum devices are 74.9% (good) and 80.2% (very good), respectively.

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