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Development of Photoelectric Effect Learning Media based on Arduino Uno

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ABSTRACT

This study aims to develop a photoelectric effect learning media based on Arduino Uno. The subjects in this study were students who took Modern Physics courses. The media development procedure uses the Borg and Gall model, which is limited to seven stages. The feasibility of the developed media refers to the results of the media expert's assessment, the level of practicality, and the effectiveness of the media. The test results show that the product's Planck constant of 6.62×10^{-34} J.s corresponds to the theoretical value. Three experts concluded that the learning media had a good level of feasibility to be used as an experimental tool. The level of practicality and effectiveness of the media showed good results. That is, practical and effective media to be used in experiments. So, it can be concluded that the Arduino Uno-based photoelectric effect learning media that has been developed is suitable for use in learning.

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I. Introduction

Physics is one of the sciences with many formulas, laws, and theories created by scientists from their discoveries [1], [2]. Stigma about the difficulty of physics subjects has been embedded in most high school, and college students, so few students do not understand the concept of physics well [3]. One theory that is quite well known among physics students is quantum theory. In quantum theory, there is a discussion of the wave-particle duality, namely light as a particle and light as a wave. This will be discussed further in the physics curriculum, which is important for learning quantum theory, namely the photoelectric effect [4], [5]. Abstract physical phenomena such as the photoelectric effect will be easier to understand with experiments.

Not all educational institutions have adequate experimental equipment facilities, one of which is the West Sulawesi University Physics Education Study Program. The implementation of the photoelectric effect practicum has never been done independently due to the unavailability of photoelectric effect practicum tools. Information and Communication Technology (ICT) cannot be separated from the physics learning process in the digital era, especially in the laboratory. The use of information and communication technology is an effective and efficient way to convey information and has great potential to improve the quality of learning, especially in displaying physical phenomena [6]. One of the uses of a microcontroller in media development is to develop a sound level meter based on Arduino Uno [7], as well as the development of Hooke law teaching aids based on Arduino Uno [8]. The study used the Arduino Uno microcontroller as an analog data processor for digital data [9]–[11]. In line with this, the use of various types of sensors to develop media has been widely carried out, such as the use of infrared sensors, magnetoresistance, sensor networks and pipelines, photodiode sensors, and Giant Magnetoresistance (GMR) Sensors [12]–[14].

There is a fundamental physical constant in the concept of the photoelectric effect. This constant is used to explain various effects in quantum theory which is very important for determining the standard for measuring electricity and mass, namely Planck's constant [15]. Not a few think that Planck's constant is an interesting thing to prove, so the measurement (h) in the International Units system is used as an experimental effort to prove its existence [16]. Many types of research on the photoelectric effect have been carried out using various research methods.

The development of instruments to explain the occurrence of the photoelectric effect with its various developments has been the research subject in recent years. For example, Garver [17] developed an economic photoelectric effect experimental apparatus using LEDs as a light source. The experimental results for determining the plank constant reached an uncertainty level of 7%. Then Risdiyanto [18] developed an experimental photoelectric effect using LED as a light source and a 1P39 vacuum phototube type where the photoelectric effect occurs. Umma and Sucahyo [19] developed a microcontroller-based photoelectric effect experiment tool with RGB LEDs as light sources and photodiodes as light sensors. This experimental tool can explain that the photoelectric effect is not affected by light intensity but is influenced by the frequency of a light source that illuminates a metal. In addition, the measured plank constant has an error of 3.8%. Putri and Ishafit [1] have developed a data acquisition system using Arduino and LabVIEW for photoelectric effect experiments. This developed system allows the automation of data collection to minimize errors. The plank constant was measured using the capacitor discharge technique on the LED. The acquisition system has been declared feasible by experts. The analysis results show the measurement error rate is less than 5%. The measured plank constant value is 6.67×10^{-34} J.s.

Based on previous research, the output or appearance of the photoelectric effect experiment is still manual. Therefore, this study designed a tool that can directly display photoelectric effect events on a laboratory scale using an LCD. The light source used is an RGB LED and a photodiode sensor as a variable for the light intensity value into a voltage value which will automatically be read on the LCD. The design of this tool uses Arduino Uno and Arduino IDE software as a controller of light intensity by the source and also a reader of the output voltage value from the sensor and uses a potentiometer as an RGB LED color variable so that it can produce various types of colors. Planck's constant can be measured 10% better using multiple LEDs ranging from 470 nm to 631 nm [10].

The RGB LED is used as a light source in this study as an LED that can emit three basic colors of light in one LED unit. The advantage of this RGB LED is that it can produce more data variations of up to six types of colors with the help of the Arduino IDE Software. So that learning is more meaningful. Another advantage of LEDs over sodium, sodium, and mercury lamps is that they are more energy-efficient and last longer, up to 50000 hours. In comparison, the mercury lamp is 10000 hours. LED lamps are not hot and do not contain ultraviolet. The choice of photodiode sensor is because this sensor can explain the photoelectric effect. So, this study aims to develop a photoelectric effect learning media that is suitable for use on a laboratory scale.

II. Theory

Learning media are all forms of physical equipment that are designed in a planned manner so that they can be used in learning and can be used by students [20]. Learning media is a tool in the teaching and learning process to stimulate the thoughts, feelings, attention, and abilities or skills of the learner so that it can encourage the learning process [21]. Based on this definition, learning media is a tool that is made in a planned manner to support the learning process.

Arduino is an electronic board that is open source so that it can make it easier for anyone who wants to create interactive and interesting projects [22]. The photodiode sensor is a light-sensitive diode. The photodiode sensor will experience a change in resistance when receiving light intensity and will flow forward electric current as a diode [23]. The photodiode is a semiconductor material where there is a p-n junction in it [24]. A photodiode sensor is a component that can be used to change the intensity value that is read from light into an electrical quantity, namely the voltage value.

In the photoelectric effect, the effect of light on electrical properties is not only due to the nature of light as an electromagnetic wave but also the nature of light as an energy carrier. In the photoelectric effect experiment, measurements were made of how the emitted electrons' rate and kinetic energy depended on the light source's intensity and wavelength [25], [26]. The light intensity only affects the large value of the current that passes through the circuit. When a suitable light is applied to one of the plates, an electric current is detected in the wire. This occurs because electrons escape from one plate and go to another plate together, where one electron absorbs a quantum of energy. One quantum of energy absorbed by the electron is used to detach from the metal and move to another metal plate. Since the electron with the highest energy cannot pass through the stopping potential, the measurement of the stopping potential or *Vs* is a way to determine the maximum kinetic energy of the electron (see eq. 1).

$$Ek_{max} = e\,V_s \tag{1}$$

Where e is the electron charge (1.6×10^{-19} C), V_s is the stopping potential in volts. The maximum kinetic energy value can be related to the frequency as shown in Eq. 2.

$$E = W_o + E_{km} \tag{2}$$
$$hv = hv_o + E_{km} \tag{3}$$
$$E_{km} = hv - hv_o \tag{4}$$

Equations 2 are called the Einstein photoelectric effect equations. Where W_o is the energy threshold of the metal work function, V_o is the threshold frequency of the metal, and v is the frequency of the light used, Ek_m is the maximum kinetic energy of electrons released from the metal and moving to another metal plates [27]. Plank's constant can be determined experimentally using Eq. 5.

$$hv = E_{km} \tag{5}$$

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$$h\frac{c}{\lambda} = E_{km} \tag{6}$$

c is the speed of light (3×10^8 m/s), and λ is the wavelength of the light source used.

Equation 6 illustrates the relationship between the wavelength of light and kinetic energy. The greater the wavelength of light, the smaller the kinetic energy because the value of kinetic energy is inversely proportional to the wavelength.

III. Method

The types of research used are Research and Development, which is a method of research used to produce specific products and test the effectiveness of the product [28]. The development is carried out using a procedural model by adapting the Borg and Gall development model. Product trials include product trial designs. The development procedure in this study adopted the seven steps of Borg and Gall, as shown in Figure 1.

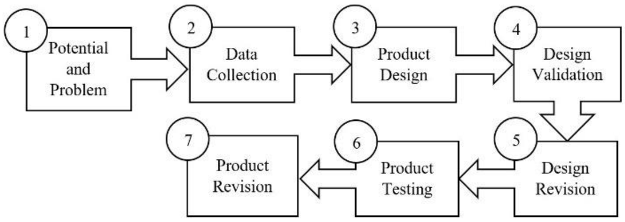

Figure 1. Seven stages of the Borg and Gall development model

The first stage: Potential and Problems. At this stage, identify potential problems in the Physics Education Laboratory of the University of West Sulawesi. Potentials and problems are obtained by observing practical tools in the laboratory, especially the availability of learning media in modern physics courses. *Second Stage: Data collection*. At this stage, collect reference sources that support the development of photoelectric effect learning media. The material for the photoelectric effect is because it is one of the materials that require practicum in learning. Arduino Uno-based learning media makes it easier for students to understand the photoelectric effect material. *Third Stage: Product Design.* The product developed is in the form of Arduino Uno-based photoelectric effect learning media. The learning media developed is adapted to the photoelectric effect material. The learning media created at this stage must be able to be a solution to the existing problems.

Fourth Stage: Product Validity. The test was carried out using a questionnaire instrument that had been provided to obtain scores and expert validators' responses to the developing learning media. The validators consist of content experts, media experts, and design experts. The results of the assessment of the development of photoelectric effect media by experts are used to improve product quality so that it is suitable for learning. After validating the product, the next step is *Design Revision*. At this stage, we improve the product according to the advice of the experts. Products that have been valid and revised will proceed to the product testing stage. *Sixth Stage: Product Trial.* The product is tested on a limited group of subjects at this stage. After being treated using Arduino Uno-based photoelectric effect learning media, users responded through a questionnaire. The last stage is to revise the product based on the suggestions at the product trial stage.

The research was conducted at the University of West Sulawesi. Subjects in this study include experts and students of Physics Education as users. The data collected in this study is quantitative data obtained through polling as a research instrument. The results of the expert assessment were analyzed using the percentage technique. The quality criteria for the photoelectric effect learning media refer to Table 1.

Table 1. Value Interval for media feasibility level

Interval (%)	Eligibility Criteria
0 – 20	Not Very Good
21 – 40	Not Good
41 – 60	Less Good
61 – 80	Good
81 – 100	Very Good

IV. Results and Discussion

The Physics Laboratory of the University of West Sulawesi has various kits or electronic components that can be used to develop photoelectric effect learning media, one of which is the Arduino Uno microcontroller. Arduino Uno is often used by physics education students in digital electronics practicum. Arduino Uno has been widely used in research on developing physics learning media [29]–[32]. In addition, using the Arduino Uno microcontroller in developing laboratory-scale learning media is relatively cheaper. This is the basis for using the Arduino Uno microcontroller as the main component in developing laboratory-scale photoelectric effect learning media.

As a follow-up to the development of learning media, the Arduino Uno-based photoelectric effect learning media was designed. This design aims to produce learning media suitable for use in modern physics practicum material on the photoelectric effect in modern physics practicum courses. Media is said to be suitable to be applied in learning if the obtained score is > 62.5% [28].

Product Design 1

At this stage, Arduino Uno is connected to several components such as photodiode sensors, RGB LEDs, 12x2 LCDs, and potentiometers. On the photodiode sensor, there are three pins connected to the Arduino Uno: Pin A0 connected to A0 on the Arduino Uno, the VCC pin connected to the 5V pin on the Arduino Uno, and the GND pin connected to the GND pin on the Arduino Uno. Then the RGB LED is connected to the Arduino, the R leg on

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the LED is connected to pin 11 PWM Arduino Uno, the G pin on the LED is connected to pin 10 PWM Arduino Uno, and the B leg on the LED is connected to pin 9 PWM Arduino Uno, and the Anode leg on the LED is connected to the Arduino Uno. Arduino Uno's GND pins.

Next, connecting the potentiometer with Arduino Uno consists of 3 potentiometers, potentiometer R is connected to pin A1 Arduino Uno, potentiometer G is connected to pin A2 on Arduino Uno, and potentiometer B is connected to pin A3 Arduino Uno. After that, connect a 12x2 LCD equipped with i2c, the VCC pin on the i2C is connected to the Arduino Uno 5V pin, the GND pin on the i2c is connected to the Arduino Uno GND pin, and the SCL pin on the i2c is connected to the Arduino Uno SCL pin, and the SDA pin on the i2c is connected. The Arduino Uno's SCL pin and the SDA pin on the i2c are connected to the Arduino Uno's SDA pin. The connection of each component is shown in Figure 2.

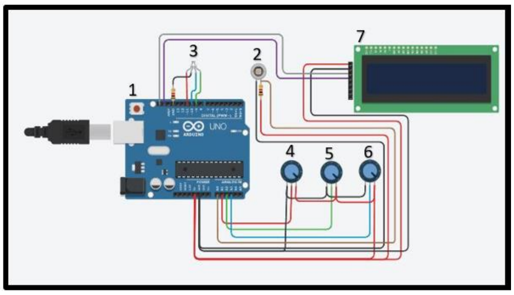

Figure 2. Photoelectric effect learning media design

The initial design of this learning media was carried out with a rough design, namely with the help of a breadboard. The initial design of this tool was carried out at the Physics Laboratory of the University of West Sulawesi as a starting place for developing photoelectric effect learning media based on Arduino Uno.

This product design aims to test the components of the tool and calibrate the tool before making the tool perfectly. Testing the components of this tool begins with making a series of learning media components based on Arduino Uno, with the help of photodiode sensors, RGB LEDs, breadboards, potentiometers, and jumper cables. Then proceed with assembling the manufacture of a programming language on the Arduino IDE application. This programming language is a command given to Arduino Uno and the components used in this development.

After this programming language is created, data collection is carried out in a dark room. Data retrieval is performed ten times for each color emitted by the RGB LED. The data from the voltage measurement generated by the photodiode sensor can be seen in Table 2.

After getting the frequency and kinetic energy values, the next step is to determine the slope of the graph between frequency and kinetic energy. The slope of the graph can be seen in Figure 3.

Table 2. Measurement data using Photodiode sensor

No	Color	Wave-length (nm)	Freq. (× 10^{14} Hz)	V (Volt)	KE (× 10^{-20} J)
1	Red	630.00	4.76	0.18	2.92
2	Red-Green	582.50	5.15	0.30	4.86
3	Green	535.00	5.61	0.40	6.48
4	Green-Blue	492.50	6.12	0.67	10.9
5	Blue	480.00	6.67	0.98	15.9
6	Red-Blue	380.00	7.85	1.20	19.4

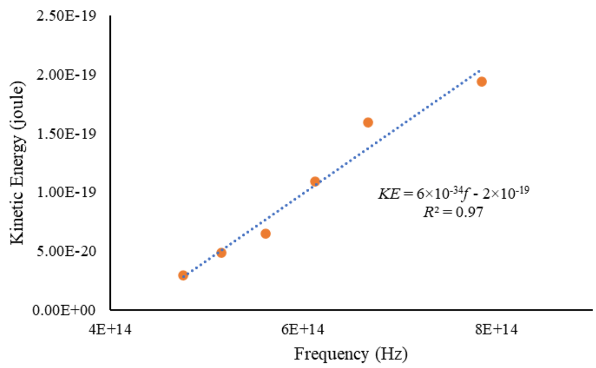

Figure 3. Relationship between kinetic energy and frequency

Product Design 2

After designing the tool and ensuring all components function properly, we perfected the learning media, starting by connecting Arduino Uno with several components such as photodiode sensors, RGB LEDs, jumper cables, and potentiometers.

The next step is to build an Arduino Uno box. This Arduino Uno box is made of acrylic material. The Arduino Uno box is designed to be opened and closed to replace the Arduino Uno or other components in case of damage. The purpose of making this Arduino Uno box is to protect the Arduino Uno and its circuit. Arduino Uno box can be seen in Figure 4.

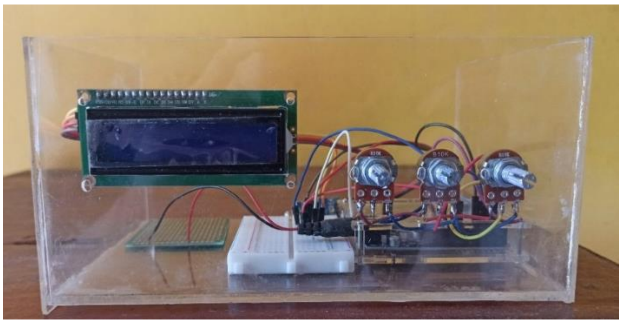

Figure 4. Photoelectric Effect Learning Media Kit box design

When viewed from above, the acrylic box contains the Arduino Uno (see Figure 5), photodiode sensor,

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potentiometer, RGB LED, LCD, and jumper cables. The LCD on the component functions as an output to display the voltage value from the photodiode sensor, the potentiometer functions as an RGB LED regulator to display various colors and the jumper cable functions as a connector for each component.

Validation

The aspects assessed in the expert validation sheet on the media include: (1) the suitability of the tool with the concept of the material taught by the lecturer, (2) the ability of the tool to improve student competence, (3) ease of maintenance, (4) accuracy, (5) Ease of operation of the tool, (6) Construction is safe for users, and (7) Has aesthetic value [33]. The results of experts' validation of the photoelectric effect learning media can be seen in Table 3.

Based on Table 3, the percentage of each aspect is in the range of 88% to 100%, including the Very Good criteria. The lowest percentage is in the first aspect, and the highest is in the second, fourth, and seventh aspects. After being analyzed as a whole, the average percentage of the quality of the learning media that has been developed is 96%, which is a very good criterion. So, the Arduino Uno-based photoelectric effect learning media meets the elements of validity and is feasible to use. In line with this research, another study that developed a physics practicum module received valid criteria from three validators [34], [35].

Product Trial

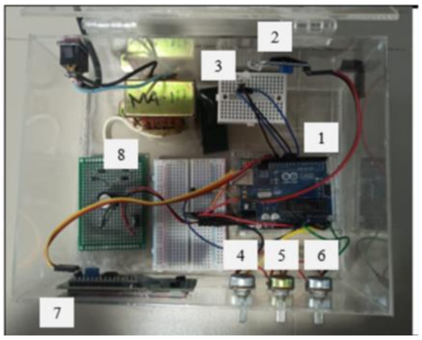
This trial was conducted at the Physics Laboratory of the University of West Sulawesi. The trial was conducted on physics education students and lecturers of modern physics practicum courses. This trial stage is a research stage to determine the practicality and effectiveness of Arduino Uno-based photoelectric effect learning media.

Practicality Level

The practical value of product development refers to the product's condition, which is easy to use by users [36]. The practicality of the learning media was obtained from the questionnaire responses of course lecturers and students to the practicality of the Arduino Uno-based photoelectric effect learning media when used in practicum or learning in class. The practicality level indicated that the materials were easy to run by teachers. The analysis results show that the developed physics teaching materials are very practical [37].

After testing the Arduino Uno-based photoelectric effect learning media with students and implementing it in a modern physics practicum, the responses of lecturers who teach modern physics are shown in Table 4.

Based on Table 4, the rating ranges from 70% to 93%. The average assessment of all aspects of lecturer responses is 85%. Because the large percentage obtained is 81%-100%, the Arduino Uno-based photoelectric effect learning media is included in the very practical category.



Information:
1. Arduino Uno
2. Photodiode Sensor
3. LED RGB
4. Potentiometer R
5. Potentiometer G
6. Potentiometer B
7. LCD 12x2 with 12c
8. Component dc voltage source

Figure 5. Photoelectric effect learning media based on Arduino Uno

Table 3. Validation results of each aspect by expert validators

No	Rated Aspect	Percentage (%)	Criteria
1	The suitability of the tool with the concept of the material taught by the subject lecturer	94	VG
2	The ability of the tool in improving student competence	100	VG
3	Ease of maintenance	92	VG
4	Accuracy	100	VG
5	Ease of operation	98	VG
6	the construction is safe for the user	88	VG
7	has an aesthetic value	100	VG
	Average	**96**	VG

Note: VG = Very Good

Table 4. The practicality of learning media is based on the lecturer's response.

No	Aspect	Percentage (%)	Criteria
1	Ease of use	93	VG
2	Increase student interest and motivation when used individually or classically.	90	VG
3	Possibility of being used for individual study by students and or teaching aids for lecturers	87	VG
4	Encourage students to think critically and solve problems.	87	VG
5	Contextuality with application in real life according to student characteristics	70	VG
	Average	**85**	VG

Note: VG = Very Good

Testing of the Arduino Uno-based photoelectric effect learning media has been carried out to determine

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student responses to the level of practicality. The results of student responses to learning media are shown in Table 5.

Based on Table 5, the average response from all aspects is 87%. Because the large percentage obtained is in the range of 81%-100%, the Arduino Uno-based photoelectric effect learning media is included in the very practical category.

Effectiveness Level

The effectiveness of learning media is obtained by taking into account four aspects of the assessment, namely: (1) Achievement of learning objectives, (2) Student enthusiasm, (3) Student involvement, and (4) Clarity of learning media [38]. The test of the effectiveness of the media to students as users was reviewed based on student feedback or responses [39], [40].

After testing the Arduino Uno-based photoelectric effect learning media to students of the physics education study program as well as carrying out modern physics practicum. The results of the course lecturers' responses to learning media are shown in Table 6.

Based on Table 6, the average of all aspects of lecturer responses is 98%. Because the large percentage obtained is 81%-100%, the Arduino Uno-based photoelectric effect learning media is included in the very effective category.

The results of student responses to the effectiveness of learning media are shown in Table 7. Based on Table 7, the average of all aspects of student responses is 88%. Because the large percentage obtained is 81%-100%, the Arduino Uno-based photoelectric effect learning media is included in the very effective category.

Table 5. The practicality of learning media is based on student responses.

No	Aspect	Percentage (%)	Criteria
1	Ease of use	93	VG
2	Students are enthusiastic about to use	89	VG
3	Giving new experience	90	VG
4	Practical to use between other Photoelectric effect learning media	89	VG
5	Photoelectric effect learning media can be used independently	73	VG
6	Learning media have the concept of the Photoelectric effect	86	VG
7	Have attractive design	86	VG
	Average	**87**	VG

Note: VG = Very Good

Table 6. Effectiveness of learning media based on lecturer's response

No	Aspect	Percentage (%)	Criteria
1	Achievement of learning objectives	100	VG
2	Student enthusiasm	100	VG
3	Student engagement	93	VG
4	Clarity of learning media	100	VG
	Average	**98**	VG

Note: VG = Very Good

Table 7. Effectiveness of learning media based on student's response

No	Aspect	Percentage (%)	Criteria
1	Relevance	89	VG
2	Interest	90	VG
3	Satisfaction	91	VG
4	Self-confident	84	VG
	Average	**88**	VG

Note: VG = Very Good

V. Conclusion

The development of Arduino Uno-based photoelectric effect learning media has been developed using the seven-stage Borg & Gall development model. Based on the data analysis and product testing results, it is known that the learning media meets the elements of validity, practicality, and good effectiveness. The results of the Plank constant test follow the theory. So, it can be concluded that the photoelectric effect learning media is feasible to be used as an experimental tool on a laboratory scale.

This research has made a significant contribution to facilitating modern physics practicum. However, empirical testing has not been carried out. Therefore, future research needs to examine how much improvement in student learning outcomes when using this learning media.

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Declarations

Author contribution	:	Hardi Hamzah is in charge of the entire research project. He also leads in the creation of photoelectric effect learning media and Collaboration with all authors. Dewi Sartika participated in delaying data collection, transcription, and analysis. He also revised the Manuscript. Muhammad Nurkhalis Agriawan is responsible for the manufacture and design of instructional media as well as in the preparation of manuscripts and analysis of research data. All authors approved the final manuscript.
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