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ARTICLE

Development of solar cell experiment for junior high school: investigating the effect of wavelength on current and voltage

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Abstract

Laboratory activities have the potential to enhance engagement through observation, experimentation, and active involvement. This study focuses on developing a solar cell experiment for junior high school students. The procedures involve measuring the dominant wavelength across various visible light spectrum and exploring the relationship between wavelength and the voltage and current output from a solar cell. The results indicate a negative correlation between wavelength and voltage/current. The highest recorded voltage and current, 1.75 V and 13.9 μA, respectively, were obtained at a wavelength of 400 nm. In contrast, the light with the highest wavelength, 650 nm, yielded the lowest recorded voltage and current, which were 1.43 V and 8.7 μA. Such laboratory activities can serve as valuable tools for teachers to impart the concept of wavelength and its real-world applications to students without the need for expensive or advance tools.

Keywords: Laboratory activity, solar cell, wavelength

1. Introduction

Science education curricula in Indonesia have been continuously improved due to the implementation of the freedom to learn curriculum (Prima et al. 2023). However, in accordance to the most recent survey, students need to be pushed to enhance their 21st century skills. According to Braaten and Sheth (2017) learning science managed by teachers fails to meet expectations due to an absence of practical skills. Fitri (2021) expressed an identical point of view, claiming that errors during experimentation and limitations in practical tools cause the teaching and learning process to run poorly, resulting in a lack of comprehension in students' minds. In most cases in Indonesia, science is presented in the classroom using only supplementary books, and students are not as involved in actual activities (Prima et al. 2023). Students must be engaged with the learning process if the goal is to achieve learning objectives and acquire a deep understanding of the lesson (Hamdani et al. 2022; Dwiyanti, Setiabudi, and Prima 2021).

Science cannot be understood by memorizing facts or by passively listening to the teacher describe concepts. Students, on the other hand, must learn through experimentation, observation, and involvement, which will ultimately foster creativity and awareness. This process is crucial for maintaining and enhancing the study of natural phenomena, and it's also important for shaping scientific attitudes (Suryawati and Osman 2017). According to Prima et al (2023), changing perceptions of the values and purposes of science learning have increasingly emphasized the importance of laboratory work.

Physics is considered a challenging subject for students to learn. Physics topics are abstract and difficult for students to learn, leading to a lack of motivation and interest (Wangchuk et al. 2023). Students also struggle with determining the equations of physics formulas used to solve problems (Qotrunnada 2022). The lack of engagement in learning physics is also considered a significant factor in students' difficulties with the subject (Ramadhani and Tanjung 2020).

Table 1. Core competencies and basic competencies in grade eight of junior high scholl

Core Comptence	Basic compentencies
Understanding knowledge (factual, conceptual, and procedural) based on curiosity about science, technology, art, culture-related phenomena, and eyesight event. [Cognitive]	Analyzing the concepts of vibration, waves, and sound in everyday life, including the human hearing system and the sonar system in animals.
	Analyzing the properties of light, the formation of shadows on the plane flat and curved and its application to explain human vision process insects, and the working principle of optical instruments.
Trying, processing, and serving in the concrete realm (using, parsing, composing, modifying, and creating) and abstract realm (writing, reading, counting, drawing, and composing) according to what was learned in schools and other sources same in point of view/theory. [Psychomotor]	Presenting experimental results on vibrations, waves, and sound Analyzing the properties of light, the formation of shadows on flat and curved planes, and their application to explain the process of human vision, insect eyes, and the working principle of optical instruments.
	Presenting experimental results about shadow formation on mirrors and lenses.

Given these conditions, this study aims to develop laboratory work that can assist school teachers in teaching the topic of wavelengths for eight grade students. The table 1 shows the core competences and basic competences in the curriculum. Wave science is perceived by students as difficult, abstract, and monotonous, often seen as a discipline suitable only for extraordinarily talented and gifted students (Erinosho 2013). The concept of wavelength will be directly implemented into real-world scenario, a mini solar cell will be used as a main tool in the laboratory work. The importance of connecting science content and skills to real-world scenarios is crucial for enhancing students' understanding and engagement (Thomas et al. 2013).

Previous study on the development and implementation of laboratory activities in learning physics concepts has been conducted. A research by Knezek and Christensen (2020)insists junior high school students to analyze home inventory appliance that consume standby power. Meanwhile, Nicolaidis (2020)developed a portable organic solar cell kit for undergraduate and high school students. A study from Prima (2023) developed a low-cost experiment regarding the measurement of light wavelength using light diffraction phenomenon. Another research shows a micro controller-based hydro static pressure experiment tool has been developed (Angjelina et al. 2023). Rosyidah, Prima, and Riandi (2023) also developed laboratory activities using tracker software to calculate the speed of propagating waves on the water surface. However, there is still no research on the development of laboratory activities to investigate the effect of wavelength on the current and voltage output in a solar cell. Through this experiment, students can become more engaged in learning the concept of waves as it relates to real-world phenomena. Furthermore, the experiment can be conducted without the need for expensive or advanced tools.

2. Method

2.1 Preparing the materials

This research needs several tools and materials which are Android phone, multi-meter, solar cell, wire, and solar power meter. These materials are shown in Figure 1. The light source for this experiment is an Android phone. Two Android phones are required, and each phone needs one application to be installed—Screen Lamp and Spectrometer. Both applications are available for free on the Google Play Store.

Figure 1. Tools and Materials

2.2 Variables

The experiment contains 3 kinds of variables which are independent, dependent, and controlled. Those variables are detailed in Table 2.

Table 2. Experiment Parameter

Parameter	Details
Independent	Wavelength variation from phone's screen (nm)
Dependent	Current (μA) and voltage (V)
Control	Light intensity of the phone's screen (0.2 W/m2), distance between phone's screen to the solar cell (15 cm)

2.3 Procedures

The development of the experiment was started from October-December 2023. After through several steps, the experiment was completely developed.The steps we have conducted were: finding novelty, determining objectives, designing experiments, providing a judgment by experts, revising, trying a trial and error, collecting and analysing data, finishing the research.

2.4 Preparing hex color and wavelength

Using the Spectrometer and Screen Lamp applications, we can measure the wavelength emitted by the phone's screen. The wavelength we want to take in this experiment ranging from 400 nm, 450 nm, 500 nm, 550 nm, 600 nm, and 650 nm. The application display is shown in Figure 2.

(a) (b)

Figure 2. The display of (a) Spectrometer and (b) Screen Lamp application

First, open the Screen Lamp application, and click the custom color button to set the hex code for the screen color. The hex color code is a six-digit code that signifies a specific color and is widely used in web design and digital media. Each pair of digits in the code represents the intensity of the color's red, green, and blue components. For instance, the hex code #FF0000 represents the color red at its maximum intensity, with no green or blue. Hex codes are frequently used to ensure consistent color representation across different digital platforms.

Second, on the other phone, open the Spectrometer application. Spectrometer allow the user to measure the dominant wavelength of the light, just by directing the camera to the light source. In this research, the source light is from Screen Lamp application, so just direct the camera from the Spectrometer application to the other phone. Set the hex code in the screen lamp application to meet the wavelength of 400nm, 450nm, 500nm, 550nm, 600nm, and 650nm.

2.5 Preparing solar power meter

Solar power meter was used to measure the light intensity of the phone screen. The light intensity needs to be the same, otherwise the current and voltage output from solar cell is not fully affected by only wavelength, but also light intensity. The distance of phone's screen to the solar power meter needs to be the same also.

2.6 Preparing solar cell

The solar cell was connected to the multimeter, ensuring the correctness of the wire connection. After obtaining the specific hex code and wavelength, current and voltage measurements were conducted. The solar cell was placed inside the dark chamber, while the multimeter remained outside. The solar cell setting is shows in Figure 3.

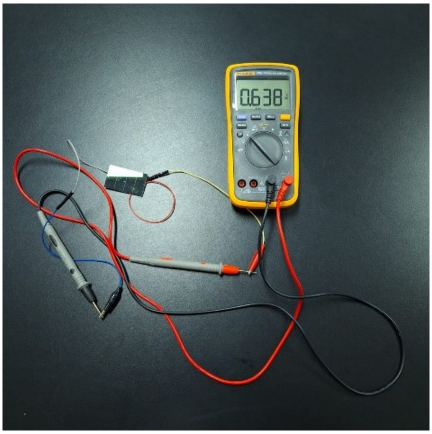

Figure 3. TThe display of (a) Spectrometer and (b) Screen Lamp application

2.7 *Preparing the cardboard box*

The measurements were conducted in a dark chamber to ensure the exclusion of any other light sources besides the phone's screen. The dark chamber was constructed using a cardboard box. On the top side of the dark chamber, there is a hole designed to accommodate the Android phone. The Android phone is positioned facing the inside of the dark chamber, ensuring that the solar cell only receives light from the phone's screen. Additionally, a small hole at the bottom ensures the connection of the wire from the multi meter. The laboratory setting is illustrated in Figure 4.

(a) (b)

Figure 4. The dark chamber and (b) laboratory setting for current and voltage measurement

2.8 *Principles of PV effect*

The electricity generation in photovoltaic (PV) is referred as PV effect. Alexandre-Edmund Becquerel, a French physicist, discovered voltage transmission in 1839 after experimenting using an electrolytic cell made up of two metal electrodes placed in an electricity-conducting solution (Petrova-Koch 2020). When exposed to light, electricity generation increased. The photovoltaic effect is the basis of solar cell technology. In 1870, the PV effect was initially studied in solids such as selenium (Dambhare, Butey, and Moharil 2021). Czochralski method for obtaining pure Silicon crystal was developed within 1940 and early 1950. This method was utilized to produce crystalline Silicon solar cells with an efficiency of up to 11% (Kymakis and Amaratunga 2003). At this time, PV effect ushered in a new era of solar power generation.

Figure 5 illustrate the principle of PV cell (Zhang and Yang 2018). Sunlight is essentially composed of photons, discrete units of energy contained in light. PV cell is constructed from semiconductor materials and features a p-n junction. When solar radiation strikes a solar cell, some photons are absorbed, leading to the creation of electron-hole pairs in the cell. Upon constructing an external circuit, the voltage difference compels electrons to move from the n-side of the junction to the p-side ((Zhang and Yang 2018). Consequently, an electric current is generated in the external circuit.

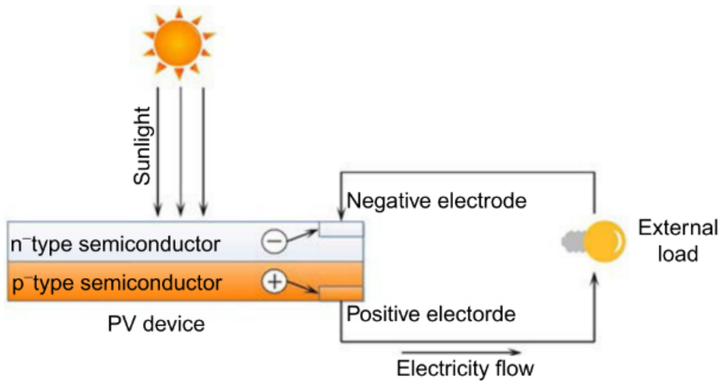

Figure 5. Principle Operation of a PV cell

3. Result and Discussion

3.1 Wavelength of hex code

By using Spectrometer application, the dominant wavelength of light can be measured. The table 2 shows the result of various hex code and its wavelength.

Table 3. Wavelength of Each Hex Code

Color	Hex Code	Wavelength (nm)
Light purple	#CE00FF	400
Purple	#8B00FE	450
Light blue	#00FEE4	500
Green	#33FF00	550
Orange	#FE9100	600
Red	#1B0000	650

The measurement of the wavelength using Spectrometer is in line with the theory of visible light spectrum. The wavelength of visible light is increasing from purple to red, ranging from 360nm to 760nm (Sliney 2016).

At the quantum level, the fundamental particle of light, including visible light, is known as the photon (Prangnell 2016). The photon has been shown to behave simultaneously as a particle and a wave; in quantum mechanics research, this is referred to as the counterintuitive wave-particle duality phenomenon (Salasnich 2017). Moreover, the photon is an elementary particle in the boson category. The energy propagated by an electromagnetic wave, for all forms of electromagnetic radiation including visible light, is continuously distributed in the form of photons. The photon energy of visible light ranges from 2 to 2.75 electron volts (eV) (Lewerenz 2013); the energy of a photon is inversely proportional to the wavelength of the electromagnetic wave.

3.2 Voltage and current output

Before measuring the voltage and current output from the solar cell, the light intensity of the phone's screen for each wavelength has been checked, and it shows 0.2 W/m². The distance from the phone's screen to the solar cell also needs to be the same; in this case, the distance is 15 cm.

The results of the measurements are shown in Table 4. Each wavelength exhibits different current and voltage outputs. The light with a wavelength of 400 nm has the highest recorded voltage and current, which are 1.75 V and 13.9 μA. Meanwhile, the light with the highest wavelength, 650 nm, has the lowest recorded voltage and current, which are 1.43 V and 8.7 μA.

Table 4. Current and Voltage Output

Wavelength (nm)	Voltage (V)	Current (μA)
400	1.75	13.9
450	1.62	11.4
500	1.59	10.2
550	1.53	9.8
600	1.48	9.4
650	1.43	8.7

3.3 Relationship between wavelength, voltage, and current

After the data was obtained, this study aimed to know the relationship between variables. The trendline of correlation graph between wavelength and voltage is shown in Figure 6. From the graph, it is found that the correlation between wavelength and voltage is negative with the equation of y = −0.0012x + 2.1907, and the contribution of wavelength toward voltage output in solar cell is 95.7%. The R2 value is 0.9577 which independent variable has a strong effect on dependent variable (King, Rosopa, and Minium 2018). The correlation is negative, means the longer the wavelength, the lower the amount of voltage produced by the solar cell. The excess value of R2 is 0.0423, or there are 4.23% factor other than wavelength that affect voltage output.

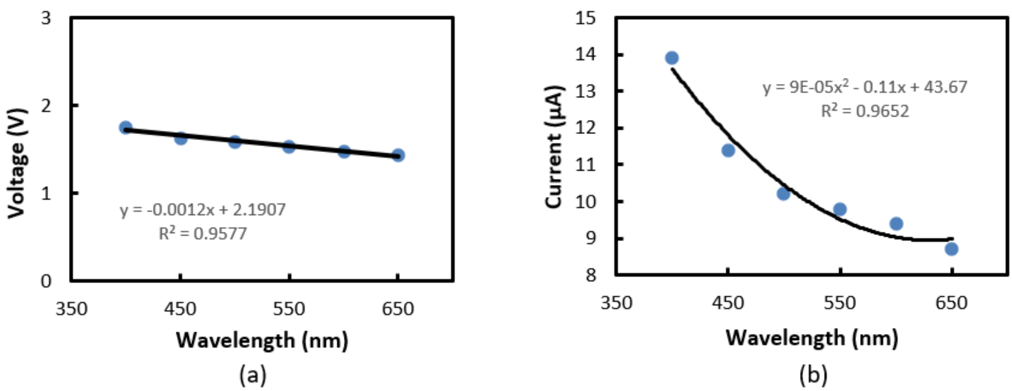

Figure 6. Correlation graph between wavelength and (a) voltage and (b) currents

The correlation between wavelength and current is also negative, represented by the equation y = 9E−05x2 – 0.11x + 43.67. Wavelength contributes significantly to the current output in the solar cell, accounting for 96.5%. The negative correlation indicates that wavelength is inversely proportional to the current output, and this relationship is further supported by the high R2 value. The excess R2 value is 0.035, indicating that factors other than wavelength contribute to 3.5% of the current output.

Based on the previous study, there are many factors that can affect solar cell output. The most crucial factor is solar cell efficiency (Huang et al. 2013). The increased efficiency of solar energy technologies and reduced investment costs have significantly boosted the popularity of solar energy generation in recent years. PV panels are renowned for their direct conversion of solar radiation into electrical energy, featuring the major advantage of having no mechanical or moving parts (Isioma, Ukpok-awaji, and Ifeanyichukwu 2021). However, they are susceptible to various environmental factors such as dust, dye, partial or total shading, and more. Among these factors, shading has the most substantial impact on PV panel efficiency. When dust, clouds, or other impediments cover the PV panels, their efficiency decreases (Brecl and Topič 2011; Ghazi and Ip 2014).

Solar cell also generally divided into three generation based on its material (Kibria et al. 2014). The first generation was based on wafer-based silicon cells, the second on thin-film technology, and the third on emerging technologies, including nano crystal-based, polymer-based, dye-sensitized, and perovskite-based solar cells (Parthiban and Ponnambalam 2022). With different types of solar cells, the recommendation for future studies is to explore various generations of solar cells to compare their voltage and current outputs, especially in school experiment settings.

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