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Smart Photosynthesis: A Light Sensor-Based Automatic Lighting System for Plant Growth Optimization as a Learning Media

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ABSTRACT
This study presents the development of an automated lighting system based on light sensors to support optimal photosynthesis in plants, particularly in low-light environments. Employing a Design-Based Research (DbR) methodology, the system was simulated using the Thinkercad Circuits platform. The prototype integrates a Light Dependent Resistor (LDR), an Arduino UNO microcontroller, and light-emitting diodes (LEDs) as artificial light sources. The simulation results demonstrate the system's ability to detect ambient light intensity in real time and activate or deactivate the lighting mechanism accordingly, based on a calibrated threshold. The findings suggest that such automation can maintain consistent light availability for plants, enhancing photosynthetic efficiency. This approach offers a cost-effective and scalable solution for smart agriculture applications, particularly in urban farming, greenhouse environments, and educational contexts. The system also holds promise for future integration into energy-efficient precision farming technologies.
Keywords: Arduino UNO, Automatic Lighting, LDR, Light Sensor, Photosynthesis

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INTRODUCTION
Photosynthesis is a key biological process in plants, converting light energy into chemical energy in the form of glucose (Nevins, 1995; Calvin, 1976; Whitmarsh & Govindjee, 1999). This process is significantly influenced by light intensity, as light serves as the primary energy source in the light reactions of photosynthesis. When plants are exposed to environmental conditions with suboptimal lighting, such as enclosed spaces, prolonged rainy seasons, densely built-up urban environments, or greenhouses with limited lighting, the rate of photosynthesis can decrease, thus inhibiting plant growth (Apriani & Wahyuni, 2020; Poorter & Pérez-Soba, 2001; Barceló-Muñoz et al., 2021; Paponov & Paponov. 2025). These conditions demonstrate that a stable light supply is a crucial factor in maintaining the efficiency of plant photosynthesis.

In the context of science and biology learning in schools, photosynthesis is often taught theoretically without learning media that demonstrate the direct relationship between light intensity and plant responses (Kamarudin et al., 2024; Yenilmez & Tekkaya, 2006; Mikkilä-Erdmann, 2001). As a result, students struggle to understand how environmental factors affect the photosynthesis process in a concrete way. Therefore, innovative learning media are needed that not only explain concepts verbally but also provide students with visual and practical experiences regarding the effect of light on photosynthesis (Nugroho & Kurniawan, 2021; Öztürk & Özdemir, 2020; Ryplova et al., 2023).

Based on these problems, this research developed a "Smart Photosynthesis" tool, namely an automatic lighting system based on a light sensor using Arduino UNO and an LDR (Light Dependent Resistor) sensor. This tool is designed to automatically detect the intensity of environmental light and activate the LED light when the surrounding conditions are too dark (Magno et al., 2014; He et al., 2020; O'Malley et al., 2010). Conversely, when the environmental light is sufficient, the light will automatically turn off. This system not only functions as a simple automation tool, but also as an interactive learning medium that can help students understand the concept of photosynthesis more concretely.

The tool, designed as a learning medium, contributes significantly because it integrates concepts from biology, physics, and technology into a single, integrated learning experience (Dyachenko et al.,2024; Verawati & Nisrina, 2025). Using this tool allows students to directly observe the relationship between light intensity and the photosynthesis needs of plants. Furthermore, this tool can increase student engagement in learning, as students not only receive theory but also observe how sensors work, changes in light intensity, and the automatic light response that represents the plant's light needs.

The use of microcontroller-based technology in learning also supports a 21st-century learning approach that emphasizes creativity, problem-solving, technological literacy, and project-based learning. With this tool, photosynthesis learning becomes more contextual, engaging, and applicable, helping students more easily grasp the concept of the factors that influence photosynthesis. Furthermore, this tool has great potential for use as a simple laboratory tool in schools due to its relatively low development costs and readily available components.

Thus, the development of an automatic lighting system based on light sensors is expected to not only help maintain stable light for plants, but also provide a significant contribution as an innovative learning medium for photosynthesis material in the classroom.

METHODS

This research is a digital simulation-based experimental study using a Design-Based Research (DbR) approach. The DbR approach was chosen because it is suitable for designing and developing technological systems, which are then tested for effectiveness in real or virtual contexts (Susilawati et al., 2025). This research was conducted through simulations on the Tinkercad Circuits platform, without physical assembly of equipment. The process followed four main stages: needs analysis, system design, development through simulation, and system performance evaluation.

The tools and materials used were entirely virtual, relying on Tinkercad Circuits' features. The main components used in this simulation include an Arduino UNO as a microcontroller for data processing and output control, a Light Dependent Resistor (LDR) sensor as a light intensity detector, and a dimmable LED as an output device for automatic lighting (Susilawati et al, 2024; Rochintaniawati et al., 2024). Additionally, a virtual 5V relay module was used as an automatic switch, along with a breadboard and virtual jumper cables to construct the electronic circuit. The programming and data monitoring processes were performed using the Arduino IDE, the Arduino microcontroller programming software. The Blynk application was not used because this simulation did not involve remote monitoring based on the Internet of Things (IoT).

The research process began with designing a circuit system in Tinkercad that would enable LED lights to automatically turn on depending on the ambient light level. An LDR sensor would read the ambient light intensity, converting the value into an analog voltage. The Arduino UNO would then process the data and compare it to a predetermined threshold value. If the ambient light was too dim (high LDR value), the LED would light up brightly at a specific intensity using PWM (Pulse Width Modulation)

If the light was bright enough, the LED would dim or turn off automatically. This entire process was controlled by program code created in the Arduino IDE and run in a Tinkercad simulation. The needs analysis stage was conducted by observing real-world conditions in a boarding house environment that frequently experiences unstable lighting. Furthermore, a literature review was conducted from journals, articles, and other reliable sources to understand the operating principles of the LDR sensor, the Arduino UNO microcontroller, and the automatic lighting control logic. Based on this analysis, appropriate tool requirements and system logic specifications were developed to address the lighting problem

The next stage is system design, which involves creating an electronic circuit schematic using Tinkercad. Components such as the Arduino UNO, LDR, LED, resistor, and virtual relay are arranged according to the design. Furthermore, the Arduino program code is written to read the LDR value, compare it to the threshold, and regulate the LED's illumination based on specific logic. This code is compiled based on relevant literature references and then modified to suit the system's needs

After the design is complete, the system is developed through a simulation. All components are assembled in the Tinkercad workspace, and the code is then uploaded to the Arduino virtual environment. The simulation is run by changing the light intensity (by adjusting the slider on the LDR) to test whether the system responds correctly to changes. The LED is expected to illuminate brightly when it's dark and dim or turn off when it's bright. This testing is repeated with varying light intensities to ensure the system functions stably.

The final stage is evaluation, which involves observing how the system responds to changes in light in the simulation. This evaluation covers several aspects, such as the system's accuracy in lighting the LED, the response time between the sensor and actuator, and the consistency of system function under various lighting conditions. The evaluation results will demonstrate the extent to which this system successfully meets its initial objectives, as well as the potential for further development if implemented physically. The subject of this research is a lighting automation system based on an Arduino UNO and an LDR, which was designed and tested virtually. The test sample consisted of varying lighting conditions, from dark to bright, manually adjusted using the LDR sensor slider in Tinkercad. This aimed to test how well the system responds to changes in ambient light intensity.

This research was conducted online, without direct testing in a physical laboratory. The simulation was conducted entirely through Tinkercad Circuits in the researcher's residential environment (a boarding house). Although not conducted in real life, this simulation was able to accurately represent the system's working processes, especially in educational and early development contexts. The research instruments used included several key elements in the simulation: an LDR sensor to read light intensity, an Arduino UNO as a logic controller, an LED as a lighting indicator, and the Arduino IDE as a programming tool. Additionally, a virtual serial monitor in Tinkercad was used to help view the analog values read by the Arduino during the simulation

Data was collected by directly observing the simulation results. Every change in light intensity on the LDR was observed and recorded, along with the LED's illumination condition. Data in the form of analog sensor values and LED illumination conditions were collected manually from the serial monitor display and visual results in Tinkercad. Documentation was done through notes and screenshots to strengthen the observations. Data analysis was conducted using descriptive qualitative and simple quantitative methods, correlating the light intensity readings with the LED illumination conditions. This analysis aimed to assess whether the system could respond to changes in light automatically and according to the desired logic. The results of this analysis served as the basis for concluding the effectiveness of the lighting automation system in the simulation and its potential application in real-world conditions. The working principle of this tool is explained through a diagram showing the program steps. The flowchart is shown in Figure 1.

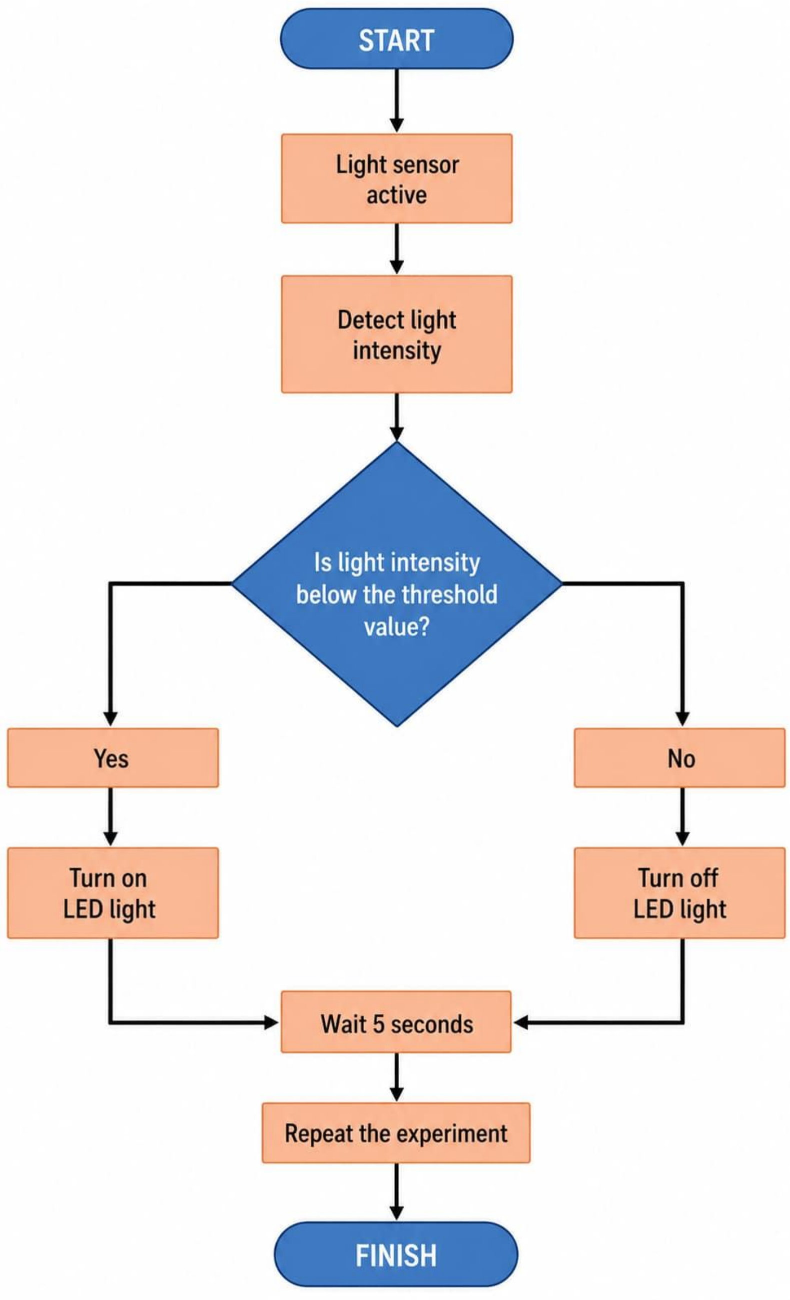

Figure 1. Flowchart

RESULT AND DISCUSSION

Analysis of the Needs of Smart Photosynthesis as a learning medium in the classroom

Figure 2 shows that photosynthesis is a vital biological process that enables plants to convert light energy into chemical energy in the form of glucose. This process occurs through light and dark reactions that occur in plant chloroplasts. According to Plant Physiology, light is the primary factor influencing the success of photosynthesis because light energy is used to drive the reactions that form ATP and NADPH, the energy sources for plant metabolism. Optimal light intensity can increase the rate of photosynthesis and plant productivity, while a lack of light can inhibit glucose formation and plant growth (Wang et al, 2022).

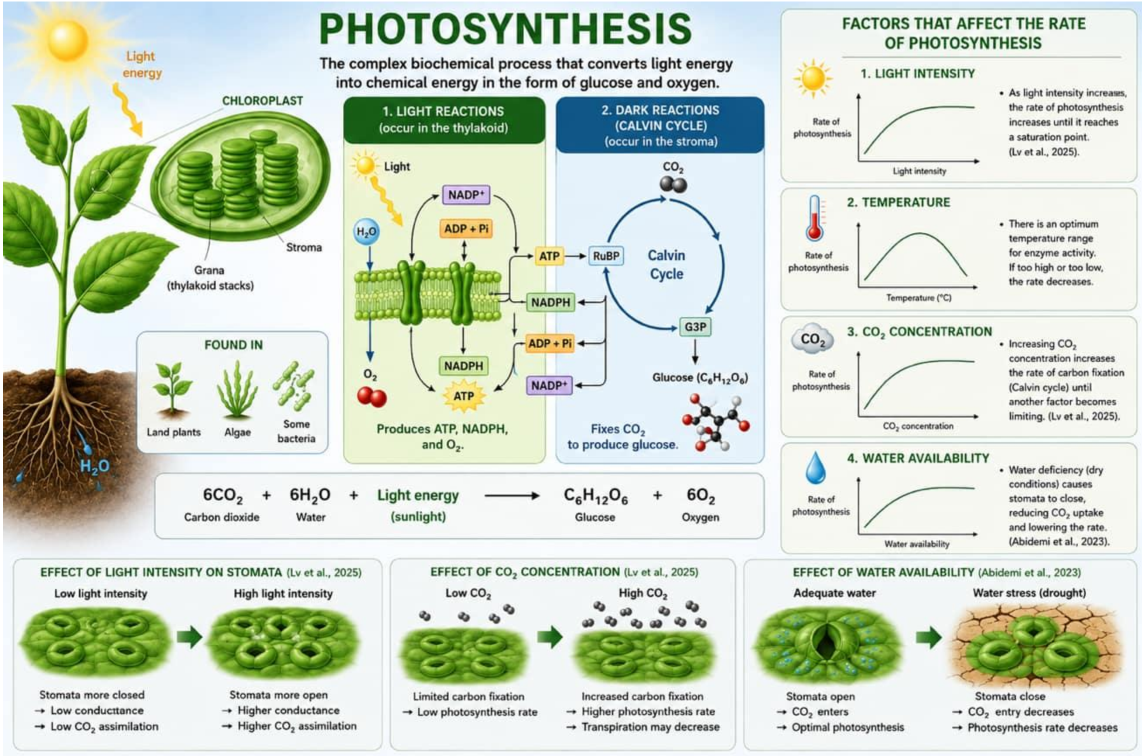

Figure 2. Photosynthesis

Several studies have shown that light intensity and quality significantly influence the effectiveness of photosynthesis. Red and blue light from LEDs can increase plant growth and photosynthetic efficiency because these two spectrums are most effectively absorbed by chlorophyll (Hasan et al., 2024). Furthermore, Little light reduces photosynthetic activity, while too much light can cause photoinhibition, which damages chloroplasts (Jiang et al., 2023). Therefore, a light regulation system is needed to maintain stable lighting intensity according to plant needs.

The development of microcontroller technology offers significant opportunities for developing automated lighting systems to support photosynthesis. One widely used technology is the Arduino UNO, as it is easy to program, economical, and compatible with various electronic sensors. Arduino UNO has the ability to read sensor data and automatically control output devices, making it suitable for use in developing learning media and smart agricultural systems (Yulianto, 2019).

Light sensors such as Light Dependent Resistors (LDRs) also play a crucial role in lighting automation systems. These sensors operate based on changes in resistance relative to the intensity of light received. When light is low, the resistance increases, producing a specific signal that can be read by the Arduino. Conversely, when light is high, the resistance decreases. The combination of an LDR and an Arduino can be used to create an automatic lighting system that responds to environmental changes (Putra et al., 2021).

Figure 3 show about in education, the use of technology-based learning media has been shown to improve conceptual understanding and student engagement in the learning process. Interactive learning media provides a more concrete learning experience than conventional lecture-based learning. In the case of photosynthesis, the use of light sensor-based tools can help students understand the relationship between light intensity and plant biological processes directly through simple laboratory observations (Cavaco et al., 2022; Silva et al., 2024).

An automatic light control system in a greenhouse demonstrated that the use of light sensors and automatic LEDs can maintain stable plant lighting in real time (Nguyen et al., 2023). This system not only improves energy efficiency but also helps maintain plant productivity under various environmental conditions. These findings support the development of the Smart Photosynthesis tool as a learning tool and simulation for smart farming technology.

In addition to functioning as an automation tool, Smart Photosynthesis also makes a significant contribution to STEM (Science, Technology, Engineering, and Mathematics)-based learning. Using this tool allows students to learn the concepts of photosynthesis, light sensors, electronic circuits, and programming in an integrated manner. This makes learning more contextual, applicable, and relevant to modern technological developments.

Based on these various studies, it can be concluded that the use of an automatic lighting system based on light sensors has great potential to support the photosynthesis process while improving the quality of science and biology learning. The integration of Arduino technology and LDR sensors into learning media can provide a more interactive, concrete, and innovative learning experience for students

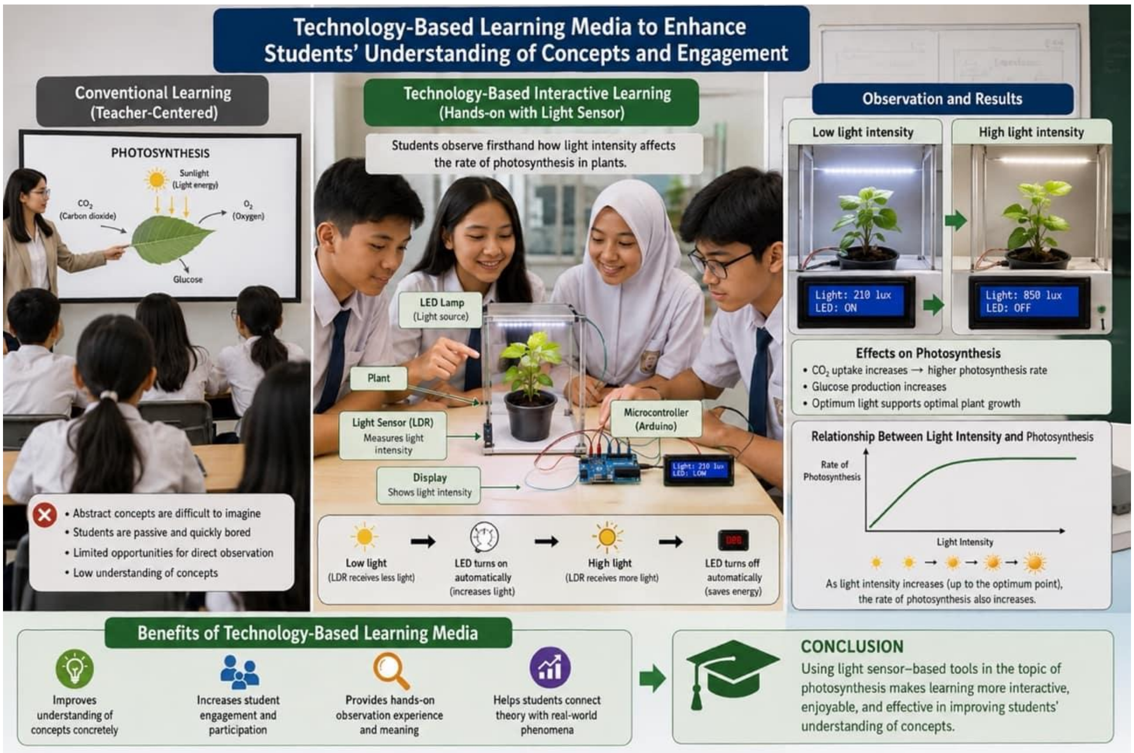

Figure 3. Technology-based learning media

Results simulation about smart photosynthesis for Plant Growth Optimization as a Learning Medium

A light sensor is a form of automation technology that detects light intensity in the surrounding environment. In this project, the light sensor is designed using the main components of a Light Dependent Resistor (LDR), an LED, and an Arduino UNO microcontroller. The LDR sensor operates based on the principle of resistance changes depending on the intensity of light it receives. When the light intensity is high (bright), the LDR's resistance decreases; conversely, when the light intensity is low (dark), its resistance increases. A 10kΩ resistor is used as a voltage divider to ensure that the LDR's resistance changes can be translated into a voltage signal that can be read by the Arduino via analog pin A0 (Putra et al., 2021).

This system is designed with simple logic, where the LDR sensor value is compared to a threshold value of 500. If the sensor reading is lower than the threshold, the environment is considered dark, and the LED connected to digital pin 7 will light up. Conversely, if the sensor value exceeds the threshold, the LED will turn off, indicating that the environment is sufficiently bright. This working principle allows the system to function as an automatic lighting detector that can be used in various daily needs, such as automatic street lighting, security systems, or room lighting controllers (Sutrisno & Purnama, 2020). Visualizations of the system simulation results are shown in Figure 4 and Figure 5. Figure 4 shows conditions when light intensity is low, causing the LED to automatically turn on. Figure 5 shows conditions when the environment is bright, causing the LED to turn off.

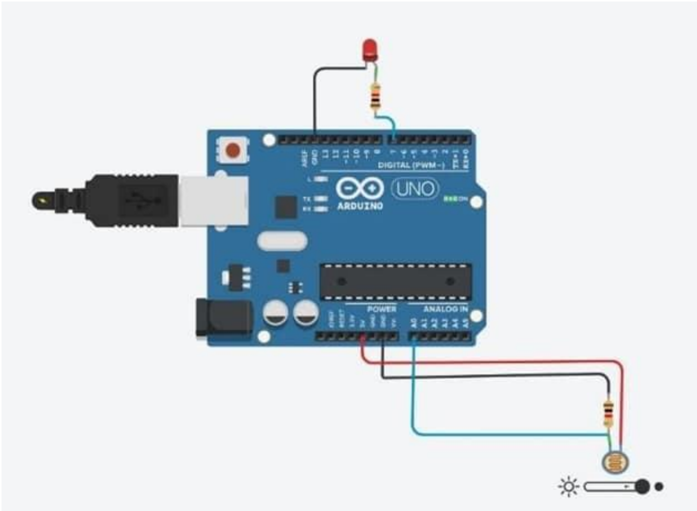

Figure 4. conditions when light intensity is low

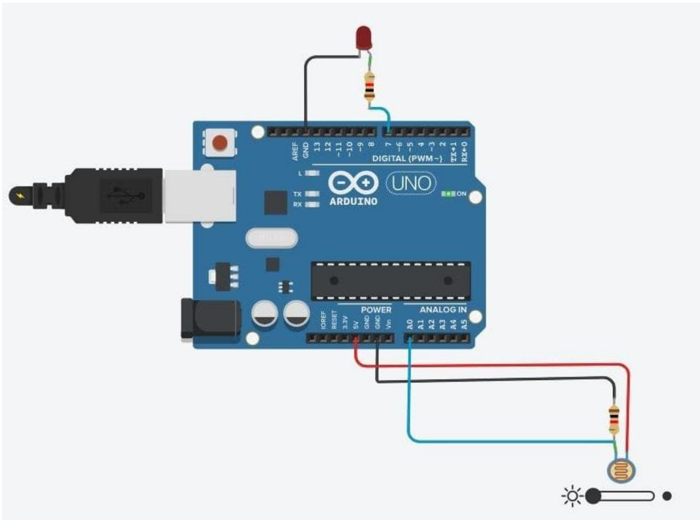

Figure 5. conditions when the environment is bright

However, this innovation is even more crucial when linked to photosynthesis, an essential biological process in plants that converts light energy into chemical energy in the form of glucose. This process requires sufficient light, along with water and carbon dioxide, as a key factor. In low-light environments, such as the rainy season, indoor spaces, or densely populated urban areas, the natural light intensity required for photosynthesis is often insufficient (Apriani & Wahyuni, 2020). This can hinder plant growth and productivity, whether in the context of agriculture, biology education, or urban farming as a hobby.

Therefore, this Arduino-based light sensor is designed not only as a general automation system but also as a supporting solution for the photosynthesis process. By detecting dark conditions, this system can automatically turn on artificial lighting to maintain light availability for plants. This way, the rate of photosynthesis can be maintained, so plants remain healthy and grow optimally even in low-light environments (Nugroho & Kurniawan, 2021).

The Arduino UNO was chosen due to its ease of programming and integration with various sensors. This platform is also supported by a large community, making it ideal for learning and prototype development. Furthermore, communication between the Arduino and the computer is conducted via a USB port, which also serves as a power source for the system (Yulianto, 2019). Simulation results from this project demonstrate that the system is capable of operating responsively, detecting changes in light and providing output in the form of an LED turning on or off, according to the predetermined programming logic.

With a simple yet effective circuit design, this light sensor project demonstrates the basic working principles of microcontroller-based automation while simultaneously having practical and ecological urgency in supporting plant survival by meeting the light requirements for photosynthesis. This project is highly relevant for use as an educational tool in electronics and biology, as well as a foundation for the development of smart farming and greenhouse systems in the future.

Simulation results showed that the Smart Photosynthesis system performed as designed. The LDR sensor successfully detected changes in ambient light intensity and sent the data to the Arduino UNO for processing. When the light intensity value fell below a predetermined threshold, the LED automatically turned on as an additional light source. Conversely, when the light intensity increased, the LED automatically turned off.

The success of this system demonstrated that the device effectively simulated the light requirements for photosynthesis. In a learning context, this device makes a significant contribution as an interactive learning tool, allowing students to directly observe how changes in light affect the automated lighting system, which represents the photosynthetic needs of plants.

This learning media has several important contributions to the learning of photosynthesis, including:

1. Visualizing the Concept of Photosynthesis Concretely
   Until now, students have tended to understand the concept of photosynthesis abstractly through theoretical explanations and illustrations in textbooks. With this tool, students can see the concrete relationship between light intensity and the plant's need for light. When the sensor detects darkness and the LED automatically lights up, students understand that plants need light for photosynthesis to continue. (Öztürk & Özdemir, 2020; Walter & Schöbel, 2023).
2. Increasing Student Activity and Engagement
   The use of sensor- and microcontroller-based tools makes learning more engaging and interactive. Students not only listen to the teacher's explanation but also observe the system's response. This activity can foster curiosity, observation skills, and motivation in photosynthesis (Ryplova et al., 2023;. Münkel-Jiménez et al., 2019).
3. Integrating STEM Learning
   The Smart Photosynthesis tool integrates elements of Science, Technology, Engineering, and Mathematics (STEM) into learning. The biological concept of photosynthesis is combined with light sensor technology and Arduino programming. This helps students understand that science can be applied in the development of simple technologies that are useful in everyday life. (Cajas, 1999; Sherman & Kurshan, 2005; Benenson, 2001).
4. Supports Practical-Based Learning
   This media can be used as a simple practical tool in the classroom or school laboratory. Teachers can utilize the tool to demonstrate the factors that influence photosynthesis, particularly light. This makes learning more contextual and less focused on memorizing concepts. (Ahmed & Pollitt, 2007; Dewi & Primayana, 2019).
5. Demonstrates Real-Life Applications of Technology
   Besides being a learning medium, this tool also demonstrates the application of automation technology in modern agriculture, such as smart farming and greenhouses. This helps students understand the relevance of photosynthesis to technological developments and

current environmental needs. (Ryplova et al., 2023). Evaluation results showed that the system demonstrated a stable and consistent response to changes in light (Susilawati et al., 2024). The Arduino UNO was able to process sensor data quickly, enabling the LEDs to turn on and off automatically without significant delay. These results align with previous research, which found that the use of light sensors and automatic control systems can help maintain plant photosynthesis efficiency and increase the effectiveness of technology-based learning. (Kamarudin et al., 2024; Öztürk, & Özdemir, 2020; Alharbi et al, 2024).

Thus, the Smart Photosynthesis device not only functions as an automated lighting system but also makes a significant contribution as an innovative learning tool for photosynthesis. This tool can help students understand concepts more concretely, increase learning engagement, and develop critical thinking skills and technological literacy in 21st-century learning.

CONCLUSION

Based on simulation results, the developed automatic lighting system successfully responded to changes in light intensity. When the surrounding environment was too dark, the LED lights automatically turned on; conversely, when there was sufficient light, the lights turned off. This system can maintain the availability of light needed for plants to photosynthesize, especially in environments with insufficient natural light. Compared with basic theory and previous research, these results align with findings that automatic light regulation can help improve plant growth efficiency. Similar systems have also proven effective in previous research, emphasizing the importance of light regulation to prevent photoinhibition and maintain plant productivity. Although testing is still simulation-based, this system shows great potential for development and real-world application, particularly on a small scale, such as in home gardens, educational laboratories, or indoor plant cultivation. Further development can be carried out through direct field trials and the integration of Internet of Things (IoT) technology so that the system can be monitored and controlled remotely.

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