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Utilization of Wokwi Technology as a Modern Electronics Learning Media

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ABSTRACT

Purpose of the study: This study aims to develop Wokwi simulation-based teaching materials using the 4D model (Define, Design, Develop, Disseminate) to improve the understanding and science process skills of physics education students.

Methodology: The Define stage identifies learning needs, while the Design stage designs interactive and easy-to-use teaching materials. In the Develop stage, the prototype is tested to assess the effectiveness of the simulation, resulting in a significant increase in students' understanding of basic concepts. This study involved 50 5th semester students at Jambi University, using questionnaires and observation sheets as instruments.

Main Findings: The results of the analysis showed that the majority of students had science process skills in the "Good" category (44%) with an average score of 78.4, while the response to the use of Wokwi was mostly in the "Quite Good" category (40%) with an average score of 65.3. The correlation test revealed a significant positive relationship ($r = 0.532$; $p = 0.001$) between the use of Wokwi and science process skills.

Novelty/Originality of this study: The novelty of this research is presenting innovation in electronics learning through the integration of Wokwi technology, which allows interactive and practical circuit simulation for students without the need for physical hardware. This study offers a new perspective in the development of technology-based digital learning media by utilizing Wokwi, which is designed to improve students' conceptual understanding and technical skills in electronics.

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1. INTRODUCTION

The development of online learning methods has encouraged the use of digital technology as a primary tool in education at the global level. In countries such as China and Singapore, technology-based simulations are starting to be widely used to help students master complex electronics concepts [1]-[5]. In Europe, especially in Germany and the UK, Python and Unity-based simulation applications are becoming a common choice for interactive teaching of electronics [6]-[8]. In Indonesia, simulation platforms such as Wokwi show great potential in supporting online learning in electronics. This application is a practical and efficient solution for educational institutions that have limited access to physical laboratories [9].

The development of Wokwi-based learning media for basic electronics material provides opportunities for students to understand the material visually and interactively [10]-[13]. With this application, students can design and test electronic circuits virtually, and change important parameters directly. The easy-to-use interface allows students to conduct independent experiments and understand the impact of each change on the circuit they create [14]-[17]. This feature helps students master more abstract electronics concepts in a more intuitive way. In addition, Wokwi allows simulation of various scenarios without the need for expensive physical laboratories.

However, the application of Wokwi in online electronics learning is not free from a number of challenges. The main challenge includes the limited availability of adequate devices among students, because this application requires a computer or laptop with certain specifications [18]-[20]. In addition, some students may not be used to using Wokwi, so additional training is needed to maximize the use of this application [21], [22]. In addition, the uneven stability of the internet network in several regions of Indonesia can hinder the smooth running of online learning with Wokwi [23], [24]. With the guidance of lecturers and appropriate training, it is hoped that these challenges can be minimized in order to create an optimal learning experience.

The use of Wokwi in electronics learning shows interesting variations across countries. In the ASEAN region, such as Thailand and Vietnam, Wokwi is widely used in universities to simulate electronic circuits in real-time, especially on the topics of microcontrollers and digital circuit design [25]-[27]. In Europe, countries like France and Italy are leveraging Wokwi for interactive simulations integrated with physical laboratory equipment, providing a hybrid experience for students [28], [29]. Meanwhile, in Indonesia, the use of Wokwi is still limited to basic circuit simulations, but various efforts are being made to develop Wokwi as a more interactive and easily accessible electronic learning medium [30], [31]. This development aims to address local challenges, such as limited laboratory equipment and the need for flexible and cost-effective learning methods.

The use of Wokwi in electronics learning provides positive benefits both in the short and long term for students. The short-term impact is an increase in student interest and involvement in learning basic electronics concepts visually [32], [33]. In the long term, this application supports the development of analytical abilities as well as problem-solving skills that are useful in the world of work [34], [35]. Students who are familiar with Wokwi will have a better understanding of electronic circuit modeling and analysis, which will be an added value in careers in technology and engineering.

Overall, the development of Wokwi-based learning media is expected to be able to overcome various obstacles in online learning in the field of electronics. Through simulations that can improve conceptual and practical understanding, students are expected to be able to achieve learning outcomes that are equivalent to direct learning in the laboratory [36], [37]. With wider access and an interactive approach, this media supports the improvement of the quality of higher education in Indonesia. This implementation is also in line with global education trends, preparing students with practical skills that are important in facing future industry needs.

Gap analysis between previous research conducted by Zakaria & Sucahyo [38] more emphasis on the application of technology in the context of engineering and physics experiments, especially in understanding the principles of fluid flow in a simulated manner. Meanwhile, this study focuses on the implementation and development of Wokwi as an electronics learning medium for students, with the main objective of improving students' theoretical understanding and practical skills in electronics through the use of an interactive and digital simulation platform. The main gap lies in the difference in the context of use: previous studies have focused more on the application of technology for physics and engineering experiments, while this study focuses more on the application of technology as a teaching aid in higher education in electronics, which offers a broader and more integrated approach to learning.

This research brings novelty to the world of electronics education by integrating Wokwi as a simulation platform to help students understand electronics concepts more interactively and practically. Unlike previous studies that focused more on developing experimental tools for specific engineering disciplines, this study highlights the use of simulation technology for broader learning, providing students with access to conduct electronics conversations and experiments without having to have expensive physical devices. In addition, this study also offers a technology-based teaching approach that can be adapted to the development of higher education curricula that increasingly prioritize digital learning.

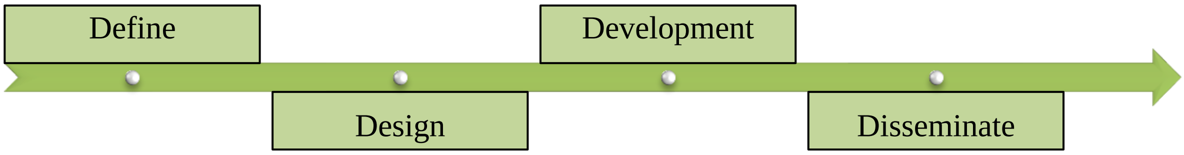
The urgency of this research lies in the need to provide a more efficient and relevant learning solution with the rapid development of technology. With the increasing dependence on digital devices, especially in education, Wokwi provides a cost-effective and easily accessible alternative for electronic circuit simulation, which is very important in the context of higher education. In addition, amidst the challenges of online learning that often limit practical experiences, this research aims to enrich the electronics learning process with a more flexible approach, allowing students to hone their practical skills even without direct access to a physical laboratory.

Based on the explanation above, the purpose of this research is to develop Wokwi simulation-based teaching materials using the 4D model (Define, Design, Develop, Disseminate) to improve the understanding and science process skills of physics education students.

2. RESEARCH METHOD

2.1. Research Design

The method used in this research is the 4D (Four-D) development model, which consists of four main stages: Define, Design, Develop, and Disseminate [39], [40]. This model was chosen because it provides a systematic structure in developing simulation-based teaching materials, allowing each stage to be carried out in a directed and consistent manner. At the Define stage, researchers identified students' learning needs and the characteristics of optical wave material in electronics that were difficult to understand through conventional methods. Furthermore, at the Design stage, the simulation framework was designed to include visual and interactive elements that could support students' intuitive understanding. This design considers the principles of visual learning so that the resulting media is effective in explaining abstract concepts in optical wave material. The steps of the 4D model used in this study are:



Gambar 1. Metode 4-D

2.1.1. Define

This stage aims to identify learning needs and determine the goals to be achieved [41]. The process begins with a needs analysis that involves collecting data from students and lecturers about their understanding of optical wave material and the challenges faced in physical practicums. Analysis of student characteristics is conducted to understand their initial level of understanding, learning needs, and possible obstacles faced in digital simulations [42], [43]. Next, content or material analysis is carried out to select the optical wave content to be simulated, such as the basic principles and applications of ultrasonic sensors. The result of this Define stage is the determination of the scope of Wokwi-based learning that suits the needs of students.

2.1.2. Design

This stage focuses on designing the structure and learning strategy to develop an effective Wokwi-based simulation. The design is carried out by considering the learning flow that makes it easier for students to understand the basic concepts of optical waves and the functionality of ultrasonic sensors [44]. Design also involves creating simulation scenarios in Wokwi that include experimental steps and clear instructions, so that students can follow the experiments independently [45]. At this stage, the visual and interactive aspects of the simulation are considered to ensure an attractive and easy-to-use display [46]. The final product of the Design stage is an initial draft of digital teaching materials which will later be tested in the development stage.

2.1.3. Develop

At this stage, Wokwi-based simulation is developed according to the design that was made at the Design stage [47], [48]. The development process begins with creating a simulation prototype that allows students to virtually learn how to operate an ultrasonic sensor [49]. The prototype was then tested internally by a number of students and lecturers to obtain input on aspects of usability, simulation accuracy, and learning effectiveness. Based on the feedback obtained, revisions and improvements were made to perfect the simulation. The validation process was also carried out by comparing the learning outcomes using the simulation with the results of the physical practicum to ensure that this simulation can accurately reflect real experiences.

The following are the stages of developing a Wokwi-based simulation for ultrasonic sensors virtually:

Figure 1. Wokwi Website Home Page View

This is the homepage of the Wokwi website (wokwi.com), which is a web-based hardware simulator for components such as Arduino, ESP32, STM32, and Raspberry Pi. Wokwi provides a variety of options for simulating electronic projects online. On this homepage, users can choose to simulate various devices, including Arduino (Uno, Mega, Nano), ESP32, STM32, and Raspberry Pi.

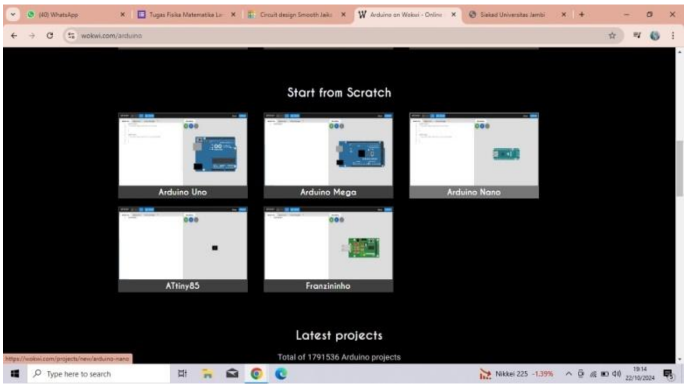


Figure 2. Start From Scratch

In this image, there are several options to start the simulation from scratch using various types of Arduino boards such as Arduino Uno, Arduino Mega, Arduino Nano, ATtiny85, and Franzininho. Users can choose the board according to their project needs and start the simulation from scratch by adding components and codes as desired.

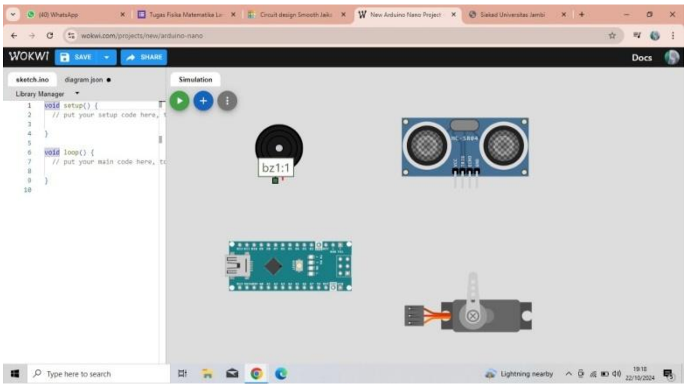


Figure 3. Tools Used

These are the tools used in the Wokwi simulation using Arduino Nano. On the screen, several connected components are visible, including a buzzer, an HC-SR04 ultrasonic sensor, and a servo motor. On the left, there is a code editor window where users can write programs in the C++ programming language used by Arduino. This simulation allows users to test the function of the circuit and code before actually implementing it on physical hardware.

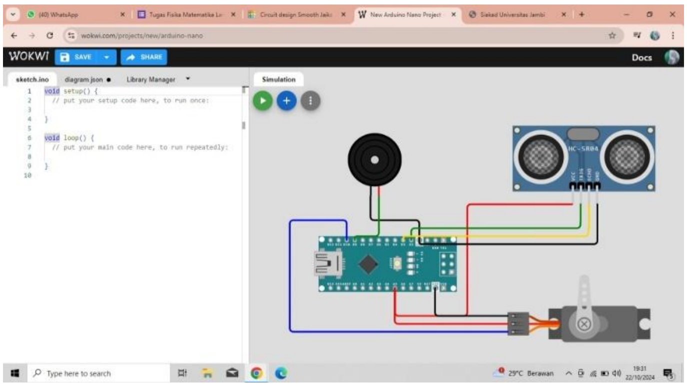


Figure 4. Library Manager Tab View

In this image, you can see the Library Manager tab in Wokwi. The Library Manager allows users to install libraries needed to perform additional functions in their Arduino projects. In this case, the user has searched for the "Servo" library to control the servo motor. The Servo library is essential in Arduino projects involving servo control because it provides functions that make it easy to adjust the angular position of the servo motor.

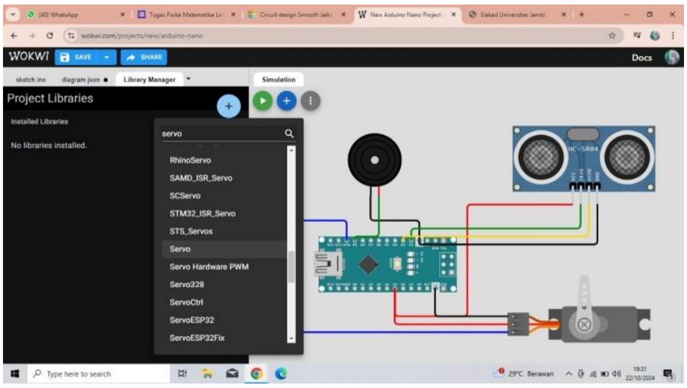


Figure 5. View From Code Editor

This is a view of the code editor in Wokwi showing part of the Arduino program code that has been written. In this code snippet, there are two functions, namely close() and open(), each of which controls the movement of the servo motor. The close() function aims to rotate the servo to a certain angle by reducing the value of the rotation variable, while the open() function rotates the servo by increasing the rotation value. Each of these functions controls the movement of the servo gradually by waiting for a delay of 100 milliseconds at each step.

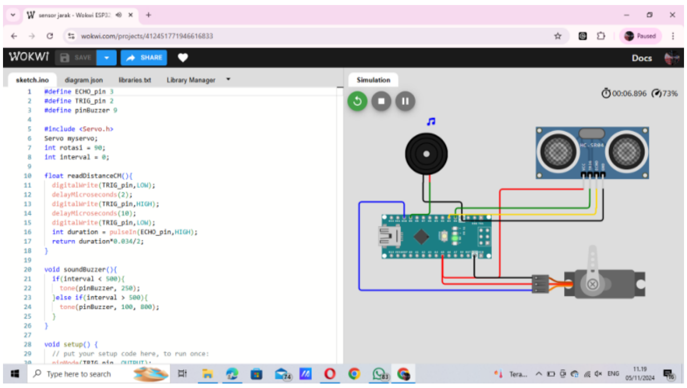


Figure 6. Simulation Results Display

The last screen shows the simulation running, including the connected components: Arduino Nano, buzzer, HC-SR04 ultrasonic sensor, and servo motor. The code written and simulated controls the movement of the servo and perhaps interacts with the ultrasonic sensor to determine when the servo will open or close. This image shows how the entire system will work in simulation to test the code and circuit before installing it on physical hardware.

2.1.4. Disseminate

The final stage in this method is dissemination, namely the distribution of Wokwi-based teaching materials to students and lecturers [50]. Dissemination is carried out through the university's e-learning platform so that students can access the simulation anytime and anywhere. In addition, dissemination also involves short training for lecturers on how to use Wokwi as a learning medium, so that they can assist students optimally. At this stage, a long-term evaluation is also prepared to see the impact of using Wokwi on student learning outcomes over a certain period of time [51], [52]. The results of the Disseminate stage are expected to provide benefits for students, lecturers, and educational institutions in developing innovative and technology-based learning methods.

This study uses a 4D development model (Define, Design, Develop, Disseminate) to develop Wokwi-based learning media on optical wave material in electronics. Up to the reported stage, the study has reached the Develop stage, where Wokwi-based simulation for ultrasonic sensors has been successfully designed, tested, and validated. The Define stage is carried out by analyzing learning needs and characteristics, while the Design stage produces an interactive simulation framework that includes visual and experimental elements. At the Develop stage, the media prototype is tested for its effectiveness and usability, with revisions based on student and lecturer input. The Disseminate stage has not been described in detail in the article, but it is proposed to disseminate the results to students and lecturers through e-learning and training platforms.

2.2. Population and Research Sample

The population in this study were 5th semester physics education students at Jambi University. Purposive sampling, also called judgment sampling, is a sampling technique by selecting samples from among the population according to what the researcher wants (objectives or problems in the study), so that the sample can represent the characteristics of the population that have been previously known. The sample criteria in this study were 5th semester physics education students who took electronics courses, especially ardiuno uno programming materials. So the sample in this study amounted to 50 5th semester physics education students at Jambi University.

2.3. Data Collection Techniques

The data collection technique in this study for matlab responses used a questionnaire sheet and for students' science process skills assessed through an observation sheet. The number of WokWi response questionnaire items consists of 20 statement items. Then for the observation sheet for students' science process skills consists of 20 assessment items. The grid for the WokWi response questionnaire and the observation sheet for students' science process skills are presented in tables 1 and 2 below:

Table 1. WokWi response questionnaire research instrument grid

No	Matlab response indicators	Item Number	Number of Items
1	Understanding of Material	1-3	3
2	Utilization of Discussion	4-6	3
3	Utilization of Companions	7-9	3
4	Understanding Awareness	10-15	6
5	Planning Experiments	16-20	5
	Number of Items		20

The following is a grid of observation sheets for students' science process skills in table 2 below:

Table 2. Science process skills observation sheet grid

No	Science Process Skills Indicators	Item Number	Number of Items
1	Observing	1, 2	2
2	Classifying	3, 4	2
3	Communicating	5, 6, 7, 8	4
4	Measuring	9, 10, 11	3
5	Planning Experiments	12	1
6	Analyzing Experiments	13	1
7	Conducting Experiments	14	1
8	Collecting and Processing Data	15	1
9	Predicting	16,17,18	3
10	Creating Data Tables	19	1
11	Conclusions	20	1
	Total		20

The categories for each variable are as follows:

Table 3. WokWi response categories and students' science process skills

Wokwi's Response		Science Process Skills	
Score Range	Category	Score Range	Category
85 - 100	Very Good	85 - 100	Very Good
69 - 84	Good	69 - 84	Good
53 - 68	Quite Good	53 - 68	Quite Good
37 - 52	Poor	37 - 52	Poor
20 - 36	Very Poor	20 - 36	Very Poor

2.4. Data Analysis Techniques

The data analysis technique in this study uses descriptive and inferential statistics. Descriptive statistics are in the form of frequency tables that include frequency, percentage, mean, median, min and max [53], [54]. Then inferential statistics in the form of assumption and hypothesis tests, namely the prerequisite test for normality and linearity. Data that is normally distributed and linear in nature meets the requirements to be able to conduct a correlation hypothesis test. Data is said to be normal and linear if the significance value obtained is more than 0.05. For hypothesis testing, data is said to have a significant relationship if the significance value found is less than 0.05.

2.5. Research Procedures

In data collection, the first thing to do is to determine the research subjects to be studied based on predetermined criteria, then distribute research instruments in the form of sheets for WokWi responses and for students' science process skills assessed through observation sheets. For the questionnaire sheet and observation sheet, this was given to 50 students in the 5th semester of Physics Education at Jambia University. Where this data collection is to analyze the effect of matlab development on the basic science process skills of physics education students at Jambi University. The data that has been obtained will be analyzed using the SPSS application with descriptive statistical tests. From this test, a conclusion will be obtained.

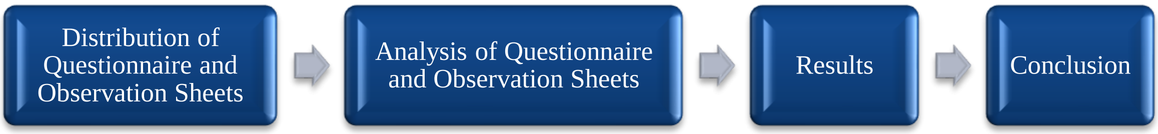


Figure 2. Research Procedure

3. RESULTS AND DISCUSSION

The following is a table of the results of the descriptive statistics of this study which includes the frequency, percentage, mean, median, minimum, and maximum for the WokWi response variables and science process skills.

Table 4. Descriptive Statistics of WokWi Responses and Science Process Skills

Variable	Interval	Category	f	%	Mean	Med	Min	Max
WokWi Response	85-100	Very Good	5	10	65.3	66	28	95
	69-84	Good	15	30				
	53-68	Quite Good	20	40				
	37-52	Not Good	7	14				
	20-36	Very Poor	3	6				
	Total		50	100.0				
Science Process Skills	85-100	Very Good	12	24	78.4	80	35	98
	69-84	Good	22	44				
	53-68	Quite Good	12	24				
	37-52	Not Good	3	6				
	20-36	Very Poor	1	2				
	Total		50	100.0				

Based on the data on the WokWi development response, the frequency distribution shows that 10.0% of students are in the Very Good category, 30.0% are in the Good category, and 40.0% are in the Fair category. Only 14.0% of students are in the Less Good category, while only 6% are in the Very Poor category. The average (mean) score for the matlab development response is 65.3 with a median of 66, a minimum value of 28, and a maximum of 95, indicating a fairly wide variation in the matlab development response.

For science process skills, 24.0% of students were categorized as Very Good, while the majority (44.0%) were in the Good category. A total of 24.0% of students were categorized as Fair Good, and 6.0% were categorized as Poor, with only 2% of students categorized as Very Poor. The mean score for science process skills was 78.4 with a median of 80, a minimum score of 35, and a maximum of 98, indicating that although many students showed good results, there were some students who were below average.

This table shows the results of the data normality test for both variables using the Kolmogorov-Smirnov test.

Table 5. Data Normality Test

Variable	Normality Test	Sig. (p-value)	Description
WokWi Response	Kolmogorov-Smirnov	0.143	Normal
Science Process Skills	Kolmogorov-Smirnov	0.086	Normal

Based on the results of the normality test, the p-value for the matlab development response is 0.143 and the p-value for science process skills is 0.086, both of which are greater than 0.05. This indicates that the data on both variables, namely matlab development response and science process skills, are normally distributed. This normal distribution indicates that the distribution of students' matlab response and science process skills data follows a balanced distribution pattern, with the majority of data being around the average.

This table shows the results of the linearity test between matlab responses and science process skills.

Table 6. Linearity Test

Independent Variable	Dependent Variable	Sig. (p-value)	Description
WokWi Response	Science Process Skills	0.032	Linear

The results of the linearity test show a significance value of 0.032, which is greater than the commonly used significance level of 0.05. This indicates that there is a significant linear relationship between the response to matlab development and science process skills.

This table presents the results of the correlation test between Matlab respin and science process skills.

Table 7. Correlation Test

Independent Variable	Dependent Variable	Correlation Coefficient (r)	Sig. (p-value)	Information
WokWi Response	Science Process Skills	0.532	0.001	Significant Positive Correlation

The results of the correlation test revealed that the correlation coefficient (r) between the matlab development response and science process skills was 0.532, with a p-value of 0.001. A p-value smaller than 0.05 indicates a significant positive relationship between the development of WokWi-based online learning and science process skills, indicating that there is an improvement with the improvement of their science process skills.

In this study, the results of the development of teaching materials using the 4D method showed quite significant effectiveness in improving student understanding. The use of the define, design, develop, and disseminate stages allows the design of materials that are more structured and in accordance with learning needs in formal schools. Evaluation at the development stage showed an increase in students' understanding of basic concepts compared to traditional learning methods. In addition, the dissemination stage showed positive acceptance from the teachers involved, who felt that these teaching materials were more supportive of the interactive learning process. Overall, the results of this study confirm that the 4D method can be used effectively in creating teaching materials that are appropriate to the context of formal education.

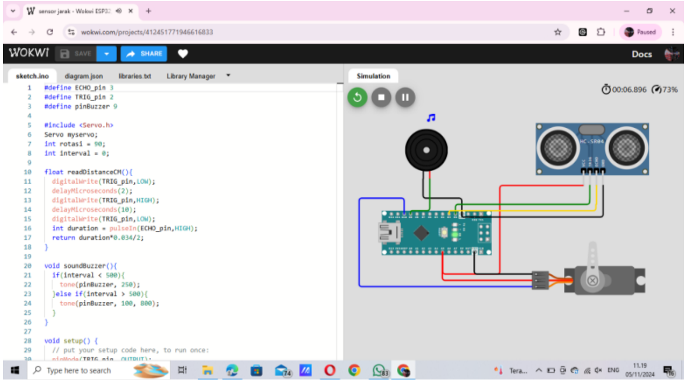


Figure 7. Simulation Results Display

Based on the simulation test displayed on Wokwi, the results show that the sensor can effectively detect distance and move the servo according to the measured distance. In addition, the use of Arduino IDE-based programming code in Wokwi allows students to see the real-time response of the circuit without having to have a physical device. This supports experiment-based learning and improves students' understanding of the basic concepts of electronics and microcontroller programming.

This research method uses a 4D (Four-D) development model consisting of four stages: Define, Design, Develop, and Disseminate. This model was chosen because it provides a structured flow for designing digital simulation-based teaching materials, especially for electronics materials [55], [56]. In the Define stage, identification of students' learning needs and mapping of challenges faced in understanding optical wave material are carried out. The Design stage then designs teaching materials in the form of Wokwi simulations, where visual and interactive elements are arranged so that students can easily access and understand electronic concepts. The Develop and Disseminate stages help ensure that this simulation can be implemented effectively, with revisions based on user input and dissemination through e-learning platforms.

The results of this study indicate that the WokWi development response and science process skills have a varied distribution among students. Most students are in the Fair and Good categories for both variables, with an average WokWi response score of 65.3 and science process skills of 78.4. The normality test shows that both variables are normally distributed, with a p-value greater than 0.05. In addition, the linearity test indicates a significant linear relationship between WokWi responses and science process skills, with a p-value of 0.032. The results of the correlation test also show a significant positive relationship ($r = 0.532$, $p = 0.001$), indicating that WokWi development contributes to improving students' science process skills.

The use of digital simulation in electronics learning shows significant variation across countries. In developed countries such as Germany and the UK, Python and Unity-based applications are widely used, enabling complex simulations with hybrid features that integrate physical devices [57], [58]. Meanwhile, in Southeast Asia, Thailand and Vietnam have been leveraging Wokwi for real-time simulation, but are more focused on microcontroller design [59], [60]. Indonesia, on the other hand, is still in the early stages of implementing Wokwi, with the main focus on basic circuit simulation. This shows a gap in terms of resource availability and the application of more advanced technologies [61], [62]. Therefore, this study positions Indonesia in an effort to catch up through more affordable and flexible simulation solutions, which are tailored to local conditions.

This research has the advantage of offering a more inclusive simulation-based learning solution through the Wokwi platform. With a simple interface and low cost, Wokwi allows students to learn independently without the need for expensive physical laboratory equipment [63], [64]. In addition, the use of the 4D development method ensures that the teaching materials produced are structured and in accordance with learning needs [65]-[67]. This approach also introduces students to interactive simulations that allow for real-time parameter manipulation, providing a richer learning experience. Another advantage is the enhancement of students' science process skills, which are essential for the world of work in technology. This research stands out because it successfully overcomes local challenges such as limited hardware and internet infrastructure through an efficient technology-based approach.

Research on the use of Wokwi technology as a modern electronic learning medium has significant benefits both locally and globally. Locally, this research can improve the quality of learning in schools or educational institutions that require easily accessible and efficient electronic practicum tools. With Wokwi, students can learn electronic concepts through interactive simulations without having to rely on expensive physical equipment. Globally, this research contributes to the development of technology-based education that can be accessed by anyone in various parts of the world. The use of Wokwi as an electronic learning medium opens up opportunities for students in areas with limited resources to gain practical experience in the field of electronics, which in turn can accelerate technological progress at the global level.

This research has a different gap from previous research which generally still focuses on the use of physical tools in electronics learning. For example, research by Mollaei et al., [68] shows that the limitations of physical tools are the main obstacle in learning electronic concepts, while this study uses simulation to overcome this obstacle. Other studies, such as those conducted by Collins et al., [69], highlighted the importance of accessibility of simulation tools, but emphasized more on paid software, which may not be affordable for all students. Compared with previous studies, this study shows that Wokwi-based simulations can be accessed more flexibly and affordably, thus reducing dependence on physical laboratory equipment.

The novelty of this research lies in the application of the Wokwi platform that allows students to interactively explore the concepts of optical waves in the context of electronics. Unlike previous studies that only offer static visualizations, Wokwi provides interactive simulations that allow manipulation of variables, such as frequency and amplitude, in real-time. Students can experiment independently with features that resemble real conditions, without the need for physical devices. This approach provides a deeper and more intuitive understanding of the working principles of sensors and electronic circuits. In addition, the use of Wokwi can increase student learning motivation, which is an important element in online learning.

This research provides important implications for the development of technology-based teaching materials, especially in electronics education in higher education. Wokwi's digital simulation helps overcome the constraints of cost and availability of physical devices, so that learning can be more flexible and affordable for students [70], [71]. However, this study has several limitations, especially in terms of dependence on internet access and students' hardware capabilities to run the simulation. In the future, the development of web-based teaching materials or mobile applications can further expand the scope of its use. In addition, further research is needed to test the effectiveness of Wokwi on other electronics concepts and in a wider range of educational contexts.

4. CONCLUSION

The use of Wokwi as a digital simulation-based learning medium has shown significant effectiveness, with an average science process skill score reaching 78.4 and the majority of students in the "Good" category (44%). In addition, 40% of students gave a "Quite Good" response to the learning experience using Wokwi, reflecting their increased understanding and engagement in learning. The applied 4D development model has succeeded in creating interactive, structured, and cost-effective learning materials, offering an innovative solution to replace the limitations of physical laboratories. Challenges such as limited hardware and internet access can be overcome through mentoring and optimization of available resources. With great potential for widespread application, Wokwi provides an opportunity for a more interactive, modern, and inclusive educational transformation in various educational institutions. Further research could develop Wokwi's integration with other hardware, such as Raspberry Pi or ESP32, to provide a more in-depth learning experience in various electronics and programming applications.

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