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Development of Electromagnetic-Based Physical Pendulum Practical Tools Using Infrared Sensors

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Abstract. Basic physics practicums often face measurement accuracy constraints due to limited tools and human error. This study aims to develop an electromagnetic-based physical pendulum practicum tool using an infrared sensor and measure its feasibility in basic physics practicum lectures 1. The method used is Research and Development (R&D) with a descriptive quantitative approach and a 3D development model. The data analysis technique uses a Likert scale with a range of 1-5 which is converted into quantitative data to calculate the percentage of feasibility. From the results of the needs analysis, 72.2% of students had difficulty in manually collecting data and supported the development of the tool. The results showed that the practicum tool was declared feasible based on the assessment of media experts with a percentage of 90% included in the very good category. Then the assessment from material experts showed a percentage of 91% included in the very good category. It can be concluded that the electromagnetic-based physical pendulum practicum tool using an infrared sensor is feasible for use in basic physics practicum activities 1 and can help overcome students' difficulties in collecting data. This study contributes to the development of electromagnetic and sensor-based technological innovations to improve the accuracy of physics practicum measurements and reduce measurement errors.

Keywords: practical tools, physical pendulum, electromagnetic field, arduino, infrared sensor

1. Introduction

Education plays a vital role as the main pillar in forming superior human resources and contributing positively to the country [1]. A quality education system is the key to preparing the next generation of the nation to face increasingly complex global dynamics. Through education, Indonesia seeks to increase the competitiveness and adaptability of its citizens to the development of the times. Each component in the education system, including various subjects, has a strategic function in shaping the character and competence of students. In this case, physics learning plays an important role not only in transferring scientific knowledge, but also in honing analytical and problem-solving skills that are very much needed in the era of rapidly developing technology.

In the world of education, especially in physics learning, technological developments have brought major changes. Physics learning that does not involve teaching aids is feared to not meet the physics learning standards set in Indonesia [2]. The use of teaching aids and interactive learning media is becoming increasingly important to visualize abstract concepts in physics and demonstrate the natural phenomena being studied. By utilizing technological developments in teaching aids, it is hoped that students' understanding of physics material can be deeper and in accordance with curriculum demands.

In the digital era like today, technological developments are increasingly rapid and affect various aspects of life [3]. In the context of education, technology plays a very crucial role, especially in improving the quality of the learning system. This significant contribution is possible because information and communication technology is able to provide comprehensive, instant, productive, and economical access to information [4]. Along with the development of technology that occurs, we have the opportunity to continue to develop and utilize it in the field of education so that the learning process becomes faster with the support of increasingly sophisticated facilities. The application of technology in science education has been proven to increase students' interest in learning because the presentation of material becomes more visually attractive, thus avoiding boredom during lessons. Most educational institutions in Indonesia have begun to adopt technology in teaching and learning activities. However, even though technology has developed rapidly, there are still challenges in its implementation in educational laboratories.

The availability of laboratory facilities in various educational institutions is quite adequate, but their utilization is still not optimal in many universities. This condition occurs due to low interest, limited knowledge about laboratory management, and less than optimal utilization of human resources available for laboratory operations [5]. Therefore, the development of innovative and easy-to-use practical tools is important to increase the effectiveness of laboratory activities. This improvement is very necessary, especially in the context of higher education where practical activities have a vital role in understanding the concept of learning.

In the reality of higher education, practical tools are still not optimally utilized as supporting instruments for learning in lectures. Especially in basic physics practical courses that cover the topic of physical pendulums, the need for effective and innovative practical tools is very significant. This is in line with the opinion of Martin, Hartini, and Ermawati in their article in 2022 which emphasized that practical tools have great potential to be implemented as learning media that are not only interesting but also provide learning experiences [6]. Thus, continuous innovation in the development and utilization of physics practical tools is a must to improve the quality of learning.

Practical activities in physics learning serve as a means to prove and apply physics concepts that have been considered abstract from books, online sources, or classroom delivery [7]. According to Carin, practical activities are an integral component of physics learning that cannot be separated. Practical work provides an opportunity for students to explore concepts that have not been previously understood through experimental proof [8]. By doing practical work, students can directly observe physics phenomena, conduct experiments, and analyze and interpret experimental data. This allows students to build a more real and in-depth understanding of the concepts learned in theory. Practical work also trains science process skills such as observing, measuring, formulating hypotheses, conducting experiments, and drawing conclusions. Practical work has an important role in strengthening the understanding of physics material, one of which is the oscillation material on a physical pendulum.

A physical pendulum can be said to be a tool consisting of a stationary pole made of iron or magnets and has a hole in the iron rod so that the position of the axis and load can be changed flexibly [9]. The concept of a physical pendulum is one of the important topics in physics learning, especially in understanding the concept of periodic motion, period, and frequency. Through physical pendulum practicums, students can directly observe the oscillation phenomenon, measure its period and frequency, and relate it to factors such as the length of the stationary pole and gravitational acceleration. This activity helps students visualize and empirically prove the concepts learned in theory. The development of physical pendulum practicum tools is important to support effective and meaningful learning.

In the physical pendulum practicum activity, students should be able to focus their observations on the oscillation phenomena that occur, analyze the pendulum motion, and understand the underlying physics concepts [10]. Measurement of the oscillation period is ideally carried out with equipment that can minimize measurement errors so that the data obtained is accurate and can be scientifically accounted for.

However, in reality, the implementation of physical pendulum practicum in the laboratory still faces various technical obstacles, especially in the data collection process which still uses manual methods using a stopwatch to calculate the pendulum swing time. Students often have difficulty in dividing their focus between observing the pendulum movement and operating the stopwatch simultaneously, which causes a high potential for human measurement error (human error). Various efforts to develop physical pendulum practicum tools have been made to overcome these problems through several previous studies.

Many studies have been conducted on the development of practical tools, especially pendulums, but what distinguishes this research from other studies such as the research conducted by Andriani. Budi, and Sunaryo in 2020 entitled "Development of Physical Pendulum Practical Tools Based on Gyroscope Sensors" is that this research also focuses more on the design of mathematical pendulum demonstration tools which are used as the basis for the tools being developed [11]. Meanwhile, the researcher's research uses the concept of a physical pendulum as the basis for the tools to be developed.

Then in the research conducted by Mariyani & Ermawati in 2023 entitled "Development of Electromagnetic Accelerator Ring Teaching Aids in Electric Magnetism Lectures on Current Magnetic Field Material" [12]. Although the theoretical concept used is the same, namely using the concept of electromagnetic fields, this research uses an electromagnetic system for ring acceleration, unlike the researcher's research which uses an electromagnetic system to control the pendulum swing motion.

Based on the results of distributing the needs analysis questionnaire to students who have studied the Basic Physics Practical Course 1 at Muhammadiyah University Prof. Dr. Hamka, the results showed that 72.2% strongly agreed and 27.8% agreed to the development of an electromagnetic-based physical pendulum practical tool for the Basic Physics Practical Course 1.

Based on the description above, the researcher conducted a study entitled "Development of Electromagnetic-Based Physical Pendulum Practical Tools Using Infrared Sensors". This study was conducted with the aim of developing electromagnetic-based physical pendulum practical tools using infrared sensors. This study was also conducted as another method to visualize the concept of a pendulum and its application in oscillation material through practical activities.

2. Method

The method used is the Research and Development (R&D) method, which is used to produce certain products and test the feasibility of the product. In this context, the product developed is a physical pendulum practicum tool based on electromagnetics using infrared sensors intended for students of the Physics Education Study Program, Muhammadiyah University Prof. Dr. Hamka.

The approach used in this study is a descriptive quantitative approach, where data obtained from the results of testing the practical tools and user responses are collected systematically, then processed and analyzed to provide an objective picture of the feasibility of the developed practical tools. This approach was chosen because it is able to provide measurable measurement results and can be scientifically accounted for.

The development model applied in this study is a 3D model modified from the 4D model developed by Thiagarajan in 1994 [13]. This 3D model consists of three main stages, namely Define, Design, and Development. The Define stage includes literature studies and needs analysis, the Design stage includes the creation of flowcharts and storyboards for practical tools, and the Develop stage involves the media validation test and material validation stages in order to determine how feasible the developed tool is.

This research was conducted from September 2024 to February 2025. This research was conducted at a University in the Jakarta area. The target of this research is active Physics Education students at Universities in the Jakarta area who have studied Basic Physics 1 and have conducted Physical Pendulum Practicum.

In evaluating the feasibility level of the electromagnetic-based physical pendulum practical tool using infrared sensors, researchers used data analysis with a Likert scale. The Likert scale is a measurement technique used to measure respondents' attitudes, opinions, and perceptions of a product or object.

The assessment instrument was designed using a Likert scale with five answer choice categories as shown in Table 1.

Table 1. Value criteria.

Percentage of Achievement	Interpretation
Very good	5
Good	4
Pretty good	3
Not good	2
Not good	1

To calculate the percentage of suitability of practical tools, the following formula is used:

$$NP = \frac{R}{SM} \text{ x } 100\,\% \qquad (1)$$

where NP = Expected feasibility percentage value R = Raw score obtained SM = Ideal maximum score. The percentage of feasibility results obtained is then interpreted based on the product feasibility criteria, as in Table 2.

Table 2. Interpretation category criteria [14].

Percentage Range Value	Predicate
81-100%	Very good
61-80%	Good
41-60%	Fairly Good
21-40%	Less good
0-20%	Not Good

3. Results and Discussion

This development research was conducted at the Physics Education Study Program, Faculty of Education and Teacher Training, Muhammadiyah University of Prof. Dr. Hamka, located on Jl. Tanah Merdeka, Ciracas District, East Jakarta City. This research was conducted using research subjects, namely students of the Physics Education Study Program who had taken the Basic Physics Practicum 1 course. The implementation time of this research started from September 2024 to February 2025.

3.1. *Define*

At this stage, a literature study was conducted as a reference in creating the product to be developed. Then the researcher conducted a needs analysis by distributing a needs analysis questionnaire to students of the Physics Education Study Program who had taken the Basic Physics Practicum 1 course and had carried out practical activities entitled Physical Pendulum.

At this needs analysis stage, it was found that 72.2% of students had difficulty in taking data manually using a stopwatch because their observation focus was divided to observe the movement of the pendulum swing and the stopwatch simultaneously. While 27.8% had no difficulty in taking data. Then there were 72.2% who strongly agreed and 27.8% who agreed to develop a physical pendulum practicum tool based on electromagnetics using infrared sensors to be used during physical pendulum practicum activities in the Basic Physics Practicum 1 course.

Based on the results of the needs analysis conducted on students of the Physics Education Study Program at Muhammadiyah University Prof. Dr. Hamka who have taken the Basic Physics Practicum 1 course, it is proven that the need for the development of a physical pendulum practicum tool based on electromagnetics using infrared sensors is needed so that it can be a solution to existing problems, and can also help facilitate students in the process of collecting data on physical pendulum practicum activities.

3.2. *Design*

The second stage is the design stage or commonly called the planning stage of the product to be developed. Display of the story board are shown in Figure 1.

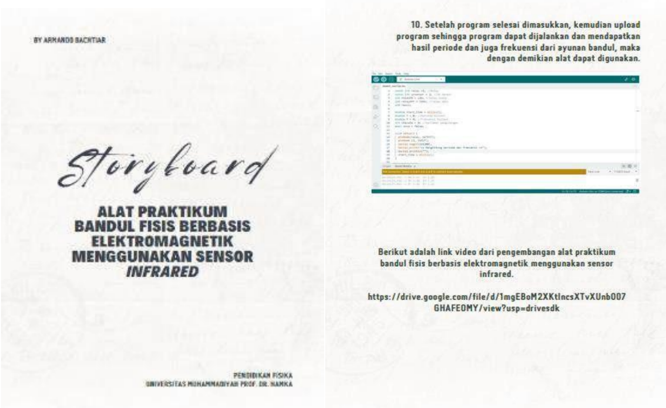

Figure 1. Practical tools story board view.

At this stage, the researcher makes a plan by creating a storyboard for a physical pendulum practicum tool based on electromagnetics using infrared sensors. The creation of the storyboard is a visualization of the physical form of the practical tools. This storyboard contains the tools and materials used and the manufacturing process, accompanied by a complete video tutorial link, so that it can be used properly and optimally.

3.3. *Development*

At this stage, the researcher began to make the tool by adjusting the results of the needs analysis and literature studies on research relevant to the research topic conducted by the researcher. The researcher developed a physical pendulum practicum tool based on electromagnetics using infrared sensors starting with preparing the basic materials used, namely acrylic, making wiring diagrams, the process of assembling the tool, uploading the program, until the final stage, namely the tool is ready to use.

At this stage, a validation test process is also carried out to determine how feasible the product is, in this case the developed practical tool. The validation test is carried out using two tests, namely the media expert validation test and the material expert validation test. Both stages of the test are carried out by including 2 validators each who are experts in their fields to validate the media and material of the tool that has been developed.

The first test stage carried out was the media expert validation test, the researcher conducted a media expert validation test in order to determine how feasible the media developed was and so that it could be implemented in the learning process, especially during the physical pendulum practicum activities. The researcher also needed advice and input from experts so that the developed tool could be said to be feasible and in accordance with the purpose of the tool being developed. The following are the recapitulation results of the media expert validation test.

Table 3. Media expert validation recapitulation.

Aspect	Before Repair		After Repair	
	Media Expert 1	Media Expert 2	Media Expert 1	Media Expert 2
Product Quality	76	80	93	100
Technical Performance	76	70	90	86
Security	70	60	90	80
Percentage Figures	74	70	91	89
Average Percentage	72		90	

From Table 3, it can be seen that media expert 1 gave a value for the product quality aspect of 76% (good), technical performance of 76% (good), and security aspect of 70% (good). Meanwhile, the average assessment results of media expert 2 for the product quality aspect were 80% (good), technical performance of 70% (good), and security aspect of 60% (good). The percentage figures given by media expert 1 were 74% and media expert 2 were 70% with an average percentage of 72% falling into the good category but still need improvement from the suggestions and input given by the experts.

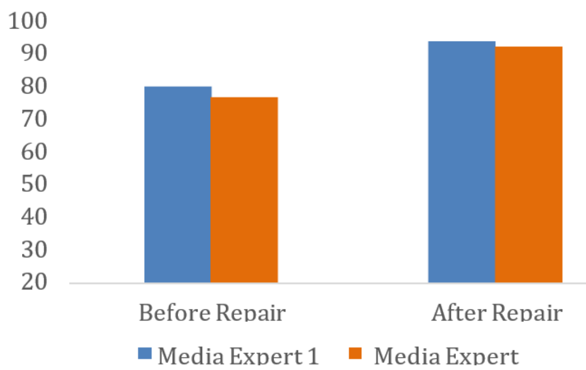

Figure 2. Media expert assessment histogram.

After completing the repairs, the value given by the expert increased with an average percentage of figures from both experts of 90% and entered the very good category. In line with the opinion expressed by Mirnawati in 2023 which stated that a media can be said to be valid if there is content and technical validity [15]. The results of the media validator assessment can be seen in Figure 2.

Figure 2 shows that the electromagnetic-based physical pendulum practicum tool using infrared sensors is said to be feasible to use without improvement based on the increase in value in the assessment given by media experts. Thus, the developed tool can be declared feasible to use in physical pendulum practicum activities in the Basic Physics Practicum 1 lecture.

The appearance of the physical pendulum practical tool based on electromagnetics using infrared sensors before and after repairs is shown in the Figure 3 and 4.

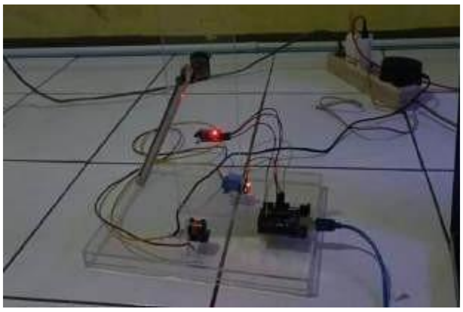

Figure 3. Tool view before repair.

Figure 4. Tool view after repair.

After conducting the media expert validation test, the next stage is the material expert validation test carried out by 2 validators who are experts in their fields. So that the results of the recapitulation of the material for the physical pendulum practical tool based on electromagnetics using infrared sensors are shown in Table 4.

Table 4. Material expert validation recapitulation.

Aspect	Before Repair		After Repair	
	Subject Matter Expert 1	Subject Matter Expert 2	Subject Matter Expert 1	Subject Matter Expert 2
Content Eligibility	70	80	90	95
Presentation of Material	70	73	95	80
Percentage Figures	70	77	93	88
Average Percentage	74		91	

From Table 4 above, it can be seen that material expert 1 gave a value for the aspect of content feasibility of 70% (good) and material presentation of 70% (good). Meanwhile, the average assessment results of material expert 2 gave a value for the aspect of content feasibility of 80% (good) and material presentation of 73% (good). The percentage figures given by media expert 1 were 70% and media expert 2 were 77% with an average percentage of 74% falling into the good category but still need improvement from the suggestions and input given by the experts.

After completing the improvements, the value given by the expert increased with an average percentage of the two experts of 91% and was included in the very good category. In line with the opinion expressed by Faridah in 2022, which stated that a module can be said to be valid and effective if an average percentage value of >70% is obtained [16]. The results of the material validator assessment can be seen in Figure 5.

Figure 5 shows that the material of the electromagnetic-based physical pendulum practicum tool using infrared sensors is said to be suitable for use without improvement based on the increase in value in the assessment given by media experts. Thus, the material of the developed tool can be declared suitable for use in physical pendulum practicum activities in the Basic Physics Practicum 1 lecture.

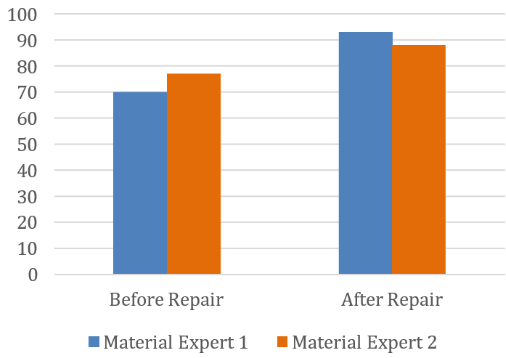

Figure 5. Histogram of material expert assessments.

The appearance of the material from the physical pendulum practical tool based on electromagnetics using infrared sensors before and after repairs are shown in Figure 6 and 7.

Figure 6. Module view before repair.

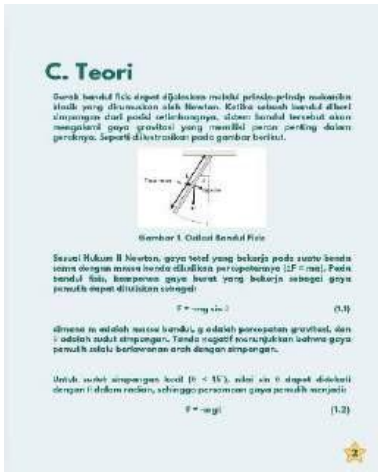

Figure 7. Module view after repair.

In the context of learning, a module can be categorized as effective if it is able to increase the capacity of students in providing a deeper conceptual understanding of the material being studied [17]. The developed physical pendulum practical module has been designed by considering systematic aspects and steps to help students understand the phenomenon of oscillation in physical pendulums and make measurements using the developed tools.

Based on the results of the media and material expert validation test, it can be said that the electromagnetic-based physical pendulum practicum tool using an infrared sensor is feasible for use and can be implemented in the Basic Physics 1 Practical course, especially when the physical pendulum practicum activity takes place. The results of this study are consistent with Putri's findings in 2022 which stated that the effectiveness and validity of learning media are greatly determined by the level of feasibility and have an impact on achieving learning objectives [18].

This is in line with research conducted by Sa'adah and Prabowo in 2022 with the title Development of Mathematical Pendulum Teaching Aids Based on Proximity Sensors on Harmonic Vibration Material for Grade X High School Students with media validation results of 94.29% and is said to be suitable for use as a learning medium on simple harmonic vibration material [19]. In addition, other research conducted by Amdani in 2025 by title Development of a Microcontroller-Based Mathematical Pendulum Teaching Aid as a Physics Learning Media on Simple Harmonic Motion Material in Class X of State Islamic Senior High School 3 Medan with media validation results of 84.99% and material of 88.88% included in the good category and said to be suitable for use in learning, especially during practical activities [20].

4. Conclusion

Based on the results of the research that has been conducted, it can be concluded that the development of a physical pendulum practical tool based on electromagnetics using infrared sensors has been successfully designed and implemented using a 3D development model (Define, Design, Development). The results of the needs analysis conducted on students of the Physics Education Study Program, as many as 72.2% of students experienced difficulties in collecting data manually and strongly agreed with the development of a physical pendulum practical tool based on electromagnetics using infrared sensors. The feasibility assessment from media experts shows that the developed practical tools obtained an average percentage assessment of 90% after improvements were made, then by material experts it was 91% after improvements which were included in the "very good" category and were declared feasible for use in physical pendulum practical activities in the Basic Physics Practical 1 lecture. The developed practical tools can be a solution to overcome problems often faced by students in data collection, especially related to limitations in the focus of observing the pendulum swing movement and recording time simultaneously, so that it can increase data accuracy to focus more on understanding the physics concepts being studied.

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