Faraday's Law Teaching Aids Using Magnetometers on Smartphone and Infrared Sensors for Electromagnetic Induction Learning

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Abstract. Faraday's law is one of the abstract physics materials. This research aims to develop Faraday's Law teaching aids by combining smartphones and infrared sensors. This study uses the Research and Development method, which refers to the ADDIE model. The teaching aids consist of a 45 cm coil whose area is, a 4000 µT neodymium permanent magnet, an Arduino integrated infrared sensor, and a smartphone's magnetometer sensor using the Phyphox application. The research trials were carried out by varying the number of coils and the height of the falling magnet. The test results obtained data in a magnetic field, the magnetic time passing through the coils, and voltage. Based on the induced emf obtained from observations and calculation results, there is an increase in the number of coils and the height of the falling magnet. This study concludes that Faraday's law teaching aids can show the effect of the number of coils and the distance of the magnet falling on the magnitude of the induced emf. The developed Faraday's law teaching aids can be used in the learning process of Faraday's law.

1. Introduction

Education is a planned-effort process of mentoring and learning for individuals to develop and grow into independent, responsible, creative, knowledgeable, healthy, and noble human beings, both seen from the physical and spiritual aspects. One of the abstract physics materials is Faraday's Law material. Students have difficulty because there is no clear explanation of abstract concepts [1]. Students find physics difficult because they have to deal with different representations such as experiments, formulas and calculations, graphs, and conceptual explanations at the same time [2]. Various supporting facilities and infrastructure are needed to realize effective physics learning. One of the supporting facilities and infrastructure is learning media.

Learning media can overcome student difficulties such as physics subjects with abstract concepts [3]. One of the learning media that can be used is teaching aids. However, some teachers prefer to explain orally and provide material to students without supporting teaching aids. The lack of teaching aids in schools is caused by several things: the high price of teaching aids and the lack of funds to buy these teaching aids [4]. One of the efforts to maximize the learning process on Faraday's law material is to use visual aids combined with a smartphone.

Currently, most students have grown up accompanied by technology such as computers, mobile phones, and video consoles in almost every activity, such as studying, working, or just entertainment [5]. Smartphones are active 24 hours on average, but not fully used for learning [6]. The proper use of smartphones helps students in obtaining information anywhere and anytime. One of the uses of
smartphones in education is sensors. The use of sensors can guide students' learning interactions with learning content to easily track students' learning interactions [7].

This article describes the development of Faraday's Law teaching aids by combining smartphones and infrared sensors. This teaching aid is expected to overcome students' difficulties in understanding Faraday's Law material. In addition, these teaching aids is expected to make it easier for teachers to carry out an interactive, economical, safe, and effective learning process.

2. Method

This study uses a research and development model. The research and development carried out referring to the stages of the ADDIE development model. The ADDIE model was chosen because of its simple steps [8]. In addition, the ADDIE model is iterative, involving review and revision during the design process [9]. The steps for developing the ADDIE model include Analyze (Analysis), Design (Planning), Development (Development), Implementation (Implementation), and Evaluation (Evaluation).

Faraday's law teaching aids are in the form of physical tools. This tool uses the help of a magnetometer to measure the field strength of the magnet used in the experiment. This tool also uses an infrared sensor to measure the time the magnet is in the coil. The developed Faraday's law props is a physics tool form that uses a magnetometer to measure the magnetic-field intensity used in the experiment. This tool is also equipped with an infrared sensor to measure the time the bar magnet is in the coil.

The analysis phase was conducted to determine the effectiveness of the Faraday law learning process and the methods used in several schools, both from the point of view of teachers and students. The analysis carried out includes several stages: analysis of student needs, analysis of teacher needs, and literature study. Based on the needs analysis results, around 70% of schools in Jakarta and Bekasi do not yet have Faraday's legal aids. The next step is to create a media design. The tools and materials to be used to develop Faraday's law teaching aids are also determined. The next step is the development stage, which includes the making of Faraday's law teaching aids, at this stage. The developed teaching aids consist of jumper cables, voltmeter, LCD screen, magnetic drop case, 300 and 600 turn coils, 4000 µT neodymium permanent magnets, magnetometer on smartphones Arduino-based infrared sensors.

![Figure 1. Faraday's law teaching aids design from the side](image1)

![Figure 2. Faraday's law teaching aids design from the front](image2)

![Figure 3. Faraday's law teaching aids design from behind](image3)

The next step is implementation. In this step, the teaching aids are tested to obtain results in a magnetic field, time and voltage. At the data collection stage, variations are made to the number of coils and the distance the magnet falls to the coil. After the implementation phase is complete, the teaching aids are evaluated regarding the effectiveness of the output results based on observations with calculations.
3. Result and Discussion
The teaching aids developed using coils with 300 and 600 turns, infrared sensors used to measure the time the magnet was in the coil, voltmeters, 4000 T neodymium magnets, prop for teaching aids, jumper cables, voltmeters, LCD screens, magnetic drop containers, as well as a magnetometer sensor on a smartphone using the phyphox application.

![Figure 4. Faraday's law teaching aids](image)

The data obtained using Faraday's law teaching aids include magnetic field strength, time, and voltage. Data retrieval is done by repetition ten times. Data were collected from varying the height (25 cm and 40 cm), a magnetic field of 4000 µT, and the number of turns of the coil (300 turns and 600 turns). The output results obtained from the voltmeter are then compared with the calculation results using the following equation [10].

\[ \varepsilon = -N \frac{A \Delta B}{\Delta t} \]

with:
- \( \varepsilon \): EMF induction (Volt)
- \( N \): Coils
- \( A \): Area (m\(^2\))
- \( \Delta B \): Magnetic field change (T)
- \( \Delta t \): Time interval (s)

3.1. Coil 300 turns at the height of 25 cm
In the experiment using a coil of 300 turns, it was carried out using a 4000 µT neodymium magnet and by dropping the magnet at the height of 25 cm. The experimental results are in the following table.
Table 1. The experiment's result used coils of 300 turns and a height of 25 cm

| No | Coils | Area (m²) | Time (s) | Magnetic Fields (T) | dB (T) | Start | Experiment Voltage (V) | Calculation Voltage (V) |
|----|-------|-----------|----------|--------------------|--------|-------|------------------------|------------------------|
| 1  | 300   | 0.001386  | 0.115    | 0.004815 0.000311 | -0.0045|       | 0.019                  | 0.016                  |
| 2  | 300   | 0.001386  | 0.105    | 0.004822 0.000265 | -0.00456|       | 0.013                  | 0.018                  |
| 3  | 300   | 0.001386  | 0.116    | 0.004729 0.000193 | -0.00454|       | 0.015                  | 0.016                  |
| 4  | 300   | 0.001386  | 0.113    | 0.004604 0.000308 | -0.0043 |       | 0.017                  | 0.016                  |
| 5  | 300   | 0.001386  | 0.114    | 0.004738 0.000332 | -0.00441|       | 0.019                  | 0.016                  |
| 6  | 300   | 0.001386  | 0.106    | 0.004751 0.000270 | -0.00448|       | 0.014                  | 0.018                  |
| 7  | 300   | 0.001386  | 0.110    | 0.004787 0.000271 | -0.00452|       | 0.015                  | 0.017                  |
| 8  | 300   | 0.001386  | 0.105    | 0.004864 0.000225 | -0.00464|       | 0.014                  | 0.018                  |
| 9  | 300   | 0.001386  | 0.113    | 0.004792 0.000227 | -0.00457|       | 0.018                  | 0.017                  |
| 10 | 300   | 0.001386  | 0.105    | 0.004808 0.000240 | -0.00457|       | 0.014                  | 0.018                  |

Average 0.0158                  0.0170

Based on the table, the average voltage obtained from the observations is 0.0158. While the average voltage from the calculation results is 0.0170. So that obtained a relative error of 16% in the experiment.

3.2. Coil 300 turns at the height of 40 cm
In the experiment using a coil of 300 turns, it was carried out using a 4000 T neodymium magnet and by dropping the magnet at the height of 40 cm. The experimental results are in the following table.

Table 2. The experiment's result used coils 300 turns and a height of 40 cm

| No | Coils | Area (m²) | Time (s) | Magnetic Fields (T) | dB (T) | Start | Experiment Voltage (V) | Calculation Voltage (V) |
|----|-------|-----------|----------|--------------------|--------|-------|------------------------|------------------------|
| 1  | 300   | 0.001386  | 0.086    | 0.005141 0.00019 | -0.00495|       | 0.027                  | 0.024                  |
| 2  | 300   | 0.001386  | 0.087    | 0.004865 0.000171| -0.00469|       | 0.024                  | 0.022                  |
| 3  | 300   | 0.001386  | 0.087    | 0.004822 0.000192| -0.00463|       | 0.028                  | 0.022                  |
| 4  | 300   | 0.001386  | 0.088    | 0.004823 0.000151| -0.00467|       | 0.026                  | 0.022                  |
| 5  | 300   | 0.001386  | 0.085    | 0.005011 0.000172| -0.00484|       | 0.024                  | 0.024                  |
| 6  | 300   | 0.001386  | 0.088    | 0.005025 0.00019 | -0.00484|       | 0.023                  | 0.023                  |
| 7  | 300   | 0.001386  | 0.091    | 0.005026 0.000185| -0.00484|       | 0.024                  | 0.022                  |
| 8  | 300   | 0.001386  | 0.090    | 0.004608 0.000212| -0.00444|       | 0.024                  | 0.020                  |
| 9  | 300   | 0.001386  | 0.086    | 0.004796 0.000136| -0.00466|       | 0.025                  | 0.023                  |
| 10 | 300   | 0.001386  | 0.087    | 0.004962 0.000151| -0.00481|       | 0.026                  | 0.023                  |

Average 0.0251                  0.022

Based on the table, the average voltage obtained from the observations is 0.0251. While the average voltage from the calculation results is 0.0225. So that obtained a relative error of 12% in the experiment.
3.3. Coil 600 turns at the height of 25 cm
In the experiment using a coil of 600 turns, it was carried out using a 4000 µT neodymium magnet and by dropping the magnet at the height of 25 cm. The experimental results are in the following table.

**Table 3.** The experiment's result used coils 600 turns and a height of 25 cm

| No | Coils | Area (m²) | Time (s) | Magnetic Fields (T) Start | Magnetic Fields (T) Finish | dB (T) | Experiment Voltage (V) | Calculation Voltage (V) |
|----|-------|-----------|---------|--------------------------|---------------------------|--------|------------------------|------------------------|
| 1  | 300   | 0.001386  | 0.105   | 0.004587                 | 0.00033                   | -0.00426 | 0.039                  | 0.034                  |
| 2  | 300   | 0.001386  | 0.105   | 0.004766                 | 0.000336                  | -0.00443 | 0.038                  | 0.035                  |
| 3  | 300   | 0.001386  | 0.107   | 0.004882                 | 0.000234                  | -0.00465 | 0.035                  | 0.036                  |
| 4  | 300   | 0.001386  | 0.104   | 0.004813                 | 0.000423                  | -0.00439 | 0.033                  | 0.035                  |
| 5  | 300   | 0.001386  | 0.100   | 0.005025                 | 0.00045                   | -0.00458 | 0.035                  | 0.038                  |
| 6  | 300   | 0.001386  | 0.104   | 0.004884                 | 0.000466                  | -0.00442 | 0.027                  | 0.035                  |
| 7  | 300   | 0.001386  | 0.103   | 0.004947                 | 0.000251                  | -0.00447 | 0.046                  | 0.038                  |
| 8  | 300   | 0.001386  | 0.104   | 0.004891                 | 0.000266                  | -0.00463 | 0.032                  | 0.037                  |
| 9  | 300   | 0.001386  | 0.107   | 0.004802                 | 0.000331                  | -0.00447 | 0.034                  | 0.035                  |
| 10 | 300   | 0.001386  | 0.106   | 0.003821                 | 0.000413                  | -0.00341 | 0.028                  | 0.027                  |

Average 0.0347 0.0350

Based on the table, the average voltage obtained from the observations is 0.0348. While the average voltage from the calculation results is 0.0350. So that obtained a relative error of 11% in the experiment.

3.4. Coil 600 turns at the height of 40 cm
In the experiment using a coil of 600 turns, it was carried out using a 4000 µT neodymium magnet and by dropping the magnet at the height of 40 cm. The experimental results are in the following table.

**Table 4.** The experiment's result used coils 600 turns and a height of 40 cm

| No | Coils | Area (m²) | Time (s) | Magnetic Fields (T) Start | Magnetic Fields (T) Finish | dB (T) | Experiment Voltage (V) | Calculation Voltage (V) |
|----|-------|-----------|---------|--------------------------|---------------------------|--------|------------------------|------------------------|
| 1  | 300   | 0.001386  | 0.086   | 0.00497                  | 0.000604                  | -0.00437 | 0.044                  | 0.043                  |
| 2  | 300   | 0.001386  | 0.087   | 0.004916                 | 0.000693                  | -0.00422 | 0.043                  | 0.039                  |
| 3  | 300   | 0.001386  | 0.087   | 0.004907                 | 0.000375                  | -0.00453 | 0.032                  | 0.043                  |
| 4  | 300   | 0.001386  | 0.088   | 0.004958                 | 0.000611                  | -0.00435 | 0.046                  | 0.043                  |
| 5  | 300   | 0.001386  | 0.085   | 0.004925                 | 0.000573                  | -0.00435 | 0.058                  | 0.042                  |
| 6  | 300   | 0.001386  | 0.088   | 0.004859                 | 0.00037                  | -0.00449 | 0.057                  | 0.041                  |
| 7  | 300   | 0.001386  | 0.091   | 0.004893                 | 0.000682                  | -0.00421 | 0.06                   | 0.040                  |
| 8  | 300   | 0.001386  | 0.090   | 0.004967                 | 0.00043                  | -0.00454 | 0.05                   | 0.043                  |
| 9  | 300   | 0.001386  | 0.086   | 0.004886                 | 0.000511                  | -0.00438 | 0.039                  | 0.042                  |
| 10 | 300   | 0.001386  | 0.087   | 0.004874                 | 0.000662                  | -0.00421 | 0.055                  | 0.040                  |

Average 0.0484 0.0417
Based on the table, the average voltage obtained from the observations is 0.0484. While the average voltage from the calculation results is 0.0417. So that obtained a relative error of 19% in the experiment.

The research trials were carried out by varying the number of coils and the height of the falling magnet. The test results obtained data in a magnetic field, the magnetic time passing through the coil and voltage. Data retrieval using Faraday's law teaching aids was carried out four times with ten repetitions. Data collection is also done by varying the number of coils and the height of the falling magnet.

The first experiment was carried out by dropping a magnet from a height of 25 cm into a coil of 300 turns with an area of . In the first experiment, data were obtained in the form of changes in the magnetic field (dB) of -0.005, time-lapse (dt) of 0.11 s, and the induced emf of 0.0158 V. Meanwhile, according to calculations, the results of the induced emf were 0.0170 V. The second experiment is done by dropping a magnet from a height of 40 cm into a coil of 300 turns with an area of . In the second experiment, data were obtained in the form of changes in the magnetic field (dB) of -0.005, time-lapse (dt) of 0.088 s, and the induced emf of 0.0251 V. Meanwhile, according to calculations, the results of the induction emf of 0.0225 V. The third experiment was carried out by dropping a magnet from a height of 25 cm into a coil of 600 turns with an area of . In the third experiment, data obtained in the form of changes in the magnetic field (dB) of -0.004, time interval (dt) of 0.105 s, and the induced emf of 0.0347 V. Meanwhile, according to calculations, the results of the induction emf of 0.0349 V. The fourth experiment was carried out by dropping a magnet from a height of 40 cm into a coil of 600 turns with an area of . In the fourth experiment, the data obtained in the form of changes in the magnetic field (dB) of -0.004, the time interval (dt) of 0.087 s, and the induction emf of 0.0484 V. Meanwhile, according to the calculation, the results of the induction emf were 0.04169 V. Based on the results of the induced emf, the results obtained from observations and calculation results increase with the increase in the number of coils and also the height of the falling magnet with a relative error of 14.5%.

![Figure 5. Graph of experiment voltage and calculation voltage](image)

Based on the research results, Faraday's law teaching aids can show the effect of the number of coils and the distance of the magnet falling on the magnitude of the induced emf. The height of the falling magnet can affect the time the magnet passes through the coil measured using an infrared sensor. The use of infrared sensors was chosen to increase the accuracy of the resulting time data. Magnetic field data retrieval is done using a magnetometer sensor available in the phyphox application. At the same time, the voltage data retrieval is obtained by using a voltmeter. After calculating using the induced emf equation, there are differences in the induced emf obtained. This is due to several things, such as the lack of accurate magnetic field data in the phyphox application. This is because the phyphox application is very dependent on the specifications of the smartphone used. In addition, the inaccuracy of the voltmeter measuring instrument also causes differences in the results of the induced emf obtained. Collecting data using electronic devices will increase accuracy in reading data so that students can manipulate and analyze the data that has been obtained [11].

Based on the results obtained from the experiment, the developed Faraday's law teaching aids can be used in the physics learning process on Faraday's Law. The use of Faraday's law teaching aids will
further assist students in overcoming misconceptions about Faraday's law material [12]. In addition, the use of cheap and easy-to-use Faraday law teaching aids can, of course, be readily accepted by students and teachers [13]. Faraday's law teaching aids that are developed will undoubtedly help students understand the material of Faraday's law. This is because teaching aids can increase the effectiveness of physics learning on Faraday's law [14]. Interactive learning in this pandemic period is necessary so that students are motivated to participate in physics learning [15]. The use of faraday law teaching aids can create activity in students. In addition, students can also analyse and compare the induced emf read by the voltmeter with the results of calculations using the induced emf equation.

4. Conclusion
Based on the research conducted, Faraday's law teaching aids can show the effect of the number of coils and the distance of the magnet falling on the amount of induced emf produced, although the results obtained are the difference between the voltage in the experiment and the voltage from the calculation results so that the developed Faraday's law teaching aids can be used for the learning process of Faraday's law.

Acknowledgments
In this section, thanks are given to several parties who helped in carrying out this research. Thank you to Physics Lecturers of the Universitas Negeri Jakarta for providing convenience in carrying out this research.

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