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Implementing R-STEM and the ISLE Model to Enhance Students' Conceptual Understanding of Magnetic Induction at Unsyiah Laboratory School

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Abstract: Many schools face difficulties in implementing science education through a practicum due to insufficient laboratory facilities and bureaucratic constraints, which hinder students' hands-on learning. To address such constraints, a new web-based remote laboratory, Remote STEM (R-STEM) platform, was introduced by the STEM Research Center. This study explores using R-STEM in learning magnetic induction using the ISLE-based STEM approach with Student Activity Sheets (LKPD) to enhance engagement. A mixed-methods research design was utilized, and 72 high school students underwent a set of experiments according to the ISLE cycle, from observations to pattern detection, explanation, predictions, and experimentation verification. The results show a high rate of students' understanding of magnetic induction, with a score in LKPD evaluation at 84%, a rate of implementation at 93%, and a score in learning activity alignment at 78.5%. In addition, pretest and posttest tests showed a learning outcome increase by 71%. This study contributes to the broader scientific educational community by demonstrating that remote laboratories can be effective in enhancing STEM learning, particularly in schools with fewer laboratory facilities.

Keywords: ISLE-based STEM; Magnetic induction; R-STEM

Introduction

The advancement of technology is driving a significant transformation in science education methods. One of the most notable innovations is the remote laboratory, which enables students to conduct online experiments without the limitations of physical facilities (Heradio et al., 2016). With internet support, this approach provides students with access to cutting-edge technology that may not be available in conventional learning environments (Zacharia et al., 2015). This concept allows experiments, demonstrations, or procedures conducted locally to be monitored and controlled remotely via the internet using a web browser (Gomes et al., 2009). To optimize the implementation of remote laboratories in science learning, the STEM Research Center at Syiah Kuala University has developed Remote STEM (RSTEM), a web-based platform designed to support more interactive, flexible,

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and accessible science learning for students (Irwandi et al., 2021).

The implementation of remote laboratories involves integrating various technologies, such as standard interfaces (DAQ, GPIB, and IoT) to connect experimental devices with web-based control systems (Letowski et al., 2020; Liguori et al., 2024; Lindsay et al., 2011). Moreover, virtual and remote laboratories have been proven to enhance students' conceptual understanding of science compared to conventional methods by providing a more flexible and interactive learning experience (Cheng et al., 2019; Potkonjak et al., 2016). The use of remote laboratories also contributes to reducing operational costs and laboratory equipment maintenance, making it a viable solution for educational institutions with limited resources (De Jong et al., 2013). Therefore, this approach has great potential to improve the quality of physics education, especially in schools with limited laboratory facilities.

In physics education, particularly in the concept of magnetic induction, the use of R-STEM provides students with the opportunity to develop a deep conceptual understanding through experiments based on the Investigative Science Learning Environment (ISLE) model. The ISLE model emphasizes inquiry-based learning through a scientific cycle that involves observation, pattern recognition, prediction-making, and experimental verification (Etkina et al., 2007; Sari et al., 2021; Ulfa et al., 2021). Previous studies have shown that inquiry-based learning can enhance students' conceptual understanding and problem-solving skills in physics (Wilcox et al., 2016). This approach is highly relevant in learning about magnetic induction, as it allows students to actively build conceptual understanding based on observations and experiments conducted through the RSTEM platform. Consequently, students not only comprehend theories but also connect them to real-world phenomena through technology-based experiments.

This study aims to explore the potential implementation of RSTEM with the ISLE model in enhancing students' understanding of the concept of magnetic induction. Through this approach, students are expected to become more engaged in the learning process and gain hands-on experience in conducting physics experiments. Previous studies have indicated that the use of remote laboratories can improve students' conceptual understanding and experimental skills compared to purely theoretical learning (Sauter et al., 2013).

Considering the aforementioned benefits, this study is expected to contribute to the field of education, particularly in developing experimental-based learning methods. Additionally, the research findings may serve as a reference for educational institutions in optimizing technology use to enhance the effectiveness of science education. As educational technology continues to evolve, R-STEM-based remote laboratories can serve as an innovative solution to overcome facility limitations and provide students with a broader experimental learning experience.

Method

This research is a mixed methods research (MMR) study. The study was conducted at SMA Laboratorium Unsyiah, specifically in the 10th-grade classes that have implemented the Merdeka Belajar Curriculum. The total number of participants in this study was 72 students, comprising two classes: X MIPAS 3 and X MIPAS 4. The implementation of this curriculum required a total of 3 sessions of 45 minutes each, aiming for a more efficient delivery of material to the students.

Before the learning process, the students were given a pretest to assess their initial understanding of the concepts of magnetic fields and magnetic induction. This pretest aimed to gauge the student's knowledge before the instructional intervention. Following the completion of the instructional sessions, a posttest was administered to measure the extent of improvement in the student's comprehension of magnetic induction. The posttest was conducted to evaluate the impact of the ISLE-based STEM learning implementation on the students' understanding of the subject matter.

Each learning activity is designed based on the ISLE model (Etkina et al., 2021, 2015, 2001), particularly in shaping the student's thought process to explore the extent of their understanding of the fundamental concepts in physics. In the instructional material for magnetic induction, the sequence begins with a very basic experiment on the properties of magnets. This is done to deepen the understanding of the physics concept of magnetic fields, where magnetic fields can originate from the magnet itself or can be induced by the flow of electric current through a wire, often referred to as magnetic induction. Students observe phenomena in their surroundings, followed by data observation, collection, and analysis using various representations, a process also known as observation.

From the observation results, students create a pattern for the observed phenomena by connecting them to physical quantities. They then explain the phenomena, both qualitatively and quantitatively. Subsequently, further experiments are planned by making predictions first, followed by experimental testing. If there are inconsistencies with the concept, revisions and repeat observations are carried out. If the experimental testing aligns with the concept, it is then applied in daily life, and development is carried out in the next stage. The ISLE model cycle is illustrated in Figure 1.

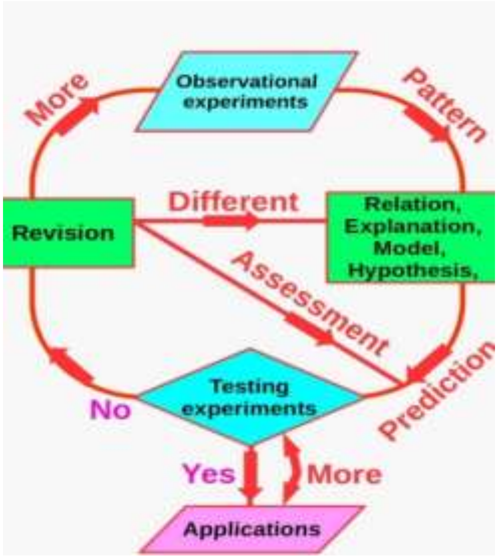

Figure 1. ISLE-based STEM development model (Etkina et al., 2001; Irwandi et al., 2018)

Observational Experiment 1

Activities for students: Students observe paramagnetic and diamagnetic materials. The task of the educator is to guide the class in using their intuition to sense the magnetic attraction power of particular materials.

Pattern

Student activities: Holding group talks to go over the trends the students saw in these observations. The task of the instructor is to get the pupils to talk about this phenomenon and look for trends. The design could take the shape of a magnet, which can attract objects from a distance but cannot attract every object because its magnetic force can pass through cardboard.

Explanation

Student exercise: Magnets can attract iron things by creating an electric field around them. This also explains diamagnetic items, which are objects that are not attracted to magnets, and ferromagnetic objects, which are objects that can be strongly attracted to a magnet. The teacher's assignment: The instructor elucidates the concept of a magnetic field.

Observational Experiment 2

Activities for students: Students observe and describe the types of attraction and repulsion at a magnet's ends. The teacher's assignment: the class uses their intuition to find magnetic poles that are adjacent to one another.

Pattern

Student exercise: In terms of reciprocal attraction and repulsion, one end of the magnet is similar to a man, and the other end is similar to a woman. Teacher's task: Students are given directions to discuss this occurrence and look for patterns in it. This pattern may take the shape of ends that resist or attract one another.

Explanation

Student exercise: In terms of reciprocal attraction and repulsion, one end of the magnet is similar to a man, and the other end is similar to a woman. Points from the instructor's manual:
(a) The instructor explains that magnetic poles are things with distinct ends. It was formerly accepted by scientists that these poles were called the north and south poles.
b. How can I figure out a magnet's north and south poles? The teacher asks the class. There are multiple methods for identifying magnetic poles, including: (1) A metallic thread is used to hang a bar magnet freely in an equilibrium state. The ends will point in the directions of the earth's north and south. (2) Styrofoam is used to cover a magnet that is positioned above the water. According to scientists, the north magnetic pole is the end of a magnet that faces northward on Earth. Conversely, the magnet's South Pole is its tip that faces the earth's South Pole. (c) A compass can be used to determine magnetic poles. After the compass has been calibrated, place one end of the magnet toward the North Pole. This is the magnet's South Pole if the compass needle is pointing in that direction. Next, rotate the magnet's opposite end. This is the north magnetic pole if there is a deviation in the compass needle.
c. Using the bar magnet used in this experiment, the teacher commands the class to label the north and south poles. Sketch the model in the worksheet.

Prediction

The fact that a magnet has a field known as a magnetic field offers to explain experiment A. A magnet has two magnetic poles: a north pole and a south pole, which is the explanation provided in experiment B. Can the students sketch or envision what a magnetic bar's magnetic field looks like? The teacher asks.

Observational Experiment 3

Student activities: Students use iron sand to describe the form of a magnetic field through experiments. Teacher's Assignment: Students are instructed to explain the magnetic field lines intuitively created by iron filings experiments.

Pattern

Activities for students: Group discussion about their next steps through the patterns that they saw from these observations. Instructor's assignment: students are expected to analyze and identify patterns of this phenomenon. This pattern could look like lines in a magnetic field.

Relation

a. There are two types of fields in physics: vector fields (which have both value and direction) and scalar fields (which have simple values). A vector field is what the magnetic field is.
b. According to scientists, "the magnetic field vector goes from the magnet's north pole to its south pole.
c. How does the magnetic field vector in a bar magnet face forward? Students explain how a magnetic bar with established north and south poles functions. Students are subsequently taught to visualize the orientation and direction of the magnetic field vector (magnetic field lines
d. Concerning the two already mentioned items, students are expected to envision or clarify the direction of the earth's magnetic field.

Observational Experiment 4

Student activities: Students observe magnetic induction experiments applied to straight wires. Teacher's assignment: Students are instructed by the teacher to build an experiment using magnetic induction on a straight wire.

Pattern

Student activities: Group discussions to go through patterns the students saw from these observations. Teacher's assignment: Students are given directions to discuss this situation and look for patterns in it. The magnetic field's direction may be shown by this pattern.

Relation

a. Magnetic fields are produced by wires that carry electric currents. Scientists concur that the term "magnetic induction" describes this phenomenon.
b. The polarization of the electric current indicates the direction of the magnetic field within the wire. Scientists generally agree that you can use the right-hand rule or Oersted's experiment to establish the direction of the magnetic field in a wire carrying an electric current. According to Oersted's tests, the following factors determine how much the compass needle's angle of deviation changes: (1) The greater the strength of the current, the more substantial the deviation angle will be. (2) The conductor-to-compass distance affects the deviation angle variation; the smaller the deviation angle, the greater the distance between the conductor and the magnetic needle. (3) The magnetic field's direction is determined by the direction of the current applied current.

Therefore, it may be said that a magnetic field can be produced by electric current. The strength of the electric current flowing through a conductor and the point's distance from it determines how strong the magnetic field is at that location (Etkina et al., 2018).

c. In theory, magnetic induction can be explained using the Biot-Savart Law which is expressed in equation (1).

$$dB = \frac{\mu_0}{4\pi}\frac{Idl\times\hat{r}}{r^2} \tag{1}$$

If dl is perpendicular to **r**, their angle is 90°, simplifying dl × r = dl. Symmetry cancels perpendicular components, leaving only the x-component as shown in equation (2).

$$dB_x = dB\cos\theta = \frac{\mu_0}{4\pi}\frac{Idl}{r^2}\cos\theta \tag{2}$$

Integrating over 2πR and substituting cos θ = R/r with $r = \sqrt{R^2 + x^2}$gives the magnetic field.

$$B_x = \frac{\mu_0}{4\pi}\frac{I}{r^2}\cos\theta \oint_0^{2\pi R} dl = \frac{\mu_0 I R^2}{2(x^2 + R^2)^{3/2}} \tag{3}$$

For multiple coils, the current scales with the turns.

d. Students must compare the experimentally and theoretically determined magnetic field strength using Equation (3), which will be analyzed with the RSTEM platform (Irwandi et al., 2021).

Prediction

Student activities: Students predict the correlation between the magnetic field's strength and coil count.

Observational Experiment 5

Student activities: Students observe magnetic induction when an electric current is applied to a 10- and 30-coil copper wire (solenoid). Teacher's assignment: Students are instructed by their teacher to develop an experiment using magnetic induction on a solenoid.

Pattern

Student activities: Discussion in groups concerning the patterns the students saw from these observations. Teacher's assignment: Students are asked to analyze this phenomenon and look for patterns in it through discussion. A nail with 10 wire turns would have a lesser magnetic pull than a nail with 30 turns, which would result in an attraction in a paperclip. This nail could be used as the pattern. The pattern in question is a general solution that can be used repeatedly to solve common problems that occur.

Explanation

Student activities: Explaining that the more coils there are in a magnetic field, the stronger the magnetic field, is how students explain the relationship between the two. Teacher's assignment: (a) Students can identify an approximate link between the number of coils and the magnetic field strength, wherein the greater the number of coils, the stronger the magnetic field. (b) The amount of magnetic field strength determined by experiment and theory must be compared by the students.

Hypothesis

Student activities: For the condition of increasing the number of coils, students have developed the notion of proportionality. By utilizing the Biot-Savart equation in computation. Teacher's assignment: The instructor guides the class in integrating intuition into logic through computations utilizing the Biot-Savart formula (Etkina et al., 2018).

$$B = \frac{\mu_0 I N}{2l} \quad (4)$$

Where:
B = Magnetic Field Strength (Wb/m² or Tesla)
I = Electric current strength (Ampere)
N = number of turns
l = solenoid length (m)
μ_0= magnetic permeability (Wb/AM)

Prediction

Student activities: Students forecast the outcomes of measurements based on the proportionality principle, and the Biot-Savart equation is used to verify their predictions. The R-STEM Platform serves as proof of the predicted outcomes. Teacher's assignment: When applying the notion of proportionality to the R_STEM platform, the instructor guides students in making predictions about the outcomes of experiments.

Explanation

Student activities: Students present the result of their effort toward constructing this comprehension. Teacher's assignment: The instructor requests that pupils showcase their accomplishments to other groups at this point. Reward or commend them for their analytical abilities.

Testing Experiment

Student activities: students conduct experiments on the R-STEM Platform to prove their hypotheses.

Task: Construct a graphical plot in Microsoft Excel based on the experiment's results. The R-STEM platform can be accessed at the link www.stemlab.ac.id. Points in the teacher's guide: The instructor assigns students to conduct experiments based on the R-STEM Platform's creation of the comparability idea.

Reflection

Student activities: Do the results of calculating these two constants together agree with the findings of the experiment? Explain!

Teacher's assignment: Students are required to explain the results of their research.

Result and Discussion

Regarding magnetic induction, the idea of magnetic characteristics and magnetic induction is where students' thought processes start. The physics idea that is being emphasized here can be thought of as follows: (a) The ability to attract items is one of the magnets' properties. (b) Poles exist in magnets. (c) The magnetic field is a directionally and value-dependent vector quantity. (d) Magnetic induction, or electric current flowing through a wire, is a method of creating a magnetic field. (e) The magnetic field's direction is determined by the electric current's direction. This can be ascertained by applying Oersted's experiment's right-hand rule. An induction magnetic substance on a straight wire was used for this experiment. (f) Magnetic induction is also influenced by the number of turns in the solenoid wire coil.

After conducting experiments based on the thinking process, students have an understanding of physics concepts about magnetic properties and magnetic induction so students are ready to conduct remote experiments using the RSTEM Platform. In this RSTEM Platform exercise, students improve their technological and computational abilities, gain a deeper understanding of physics topics, and learn how to analyze quantitative data like a scientist.

The STEM-based technology learning media used is Remote Laboratory. This instrument can able to accessed from a distance, where the instrument is located in the STEM laboratory of Unsyiah and users can be in other locations or educational institutions (Figure 2).

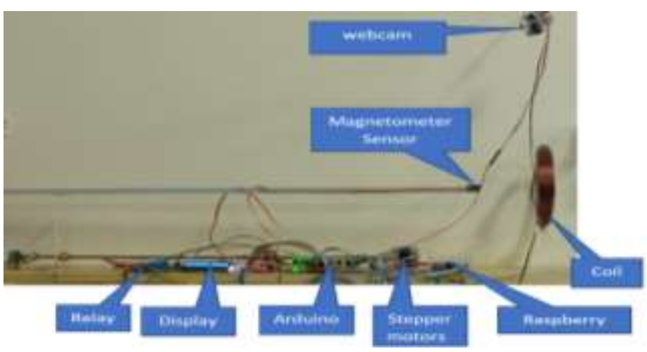

Figure 2. The magnetic induction experiment apparatus based on R-STEM involves the use of electric current

Modular hardware in this demonstration tool consists of a Raspberry PI, Arduino Uno, display, relay module, stepper driver, servo motor, thread bar, QMC 5883 sensor, and camera. Raspberry PI 4 which is a single-board computer (SBC) is used to replace a personal computer (PC) as a server, Arduino Uno is used to control the movement of the stepper motor and servo motor. The thread bar is custom-made to detect the magnetic field using a QMC5883 sensor driven by a DC motor. The camera is used to detect the movement and process of the experiment remotely (Irwandi et al., 2021).

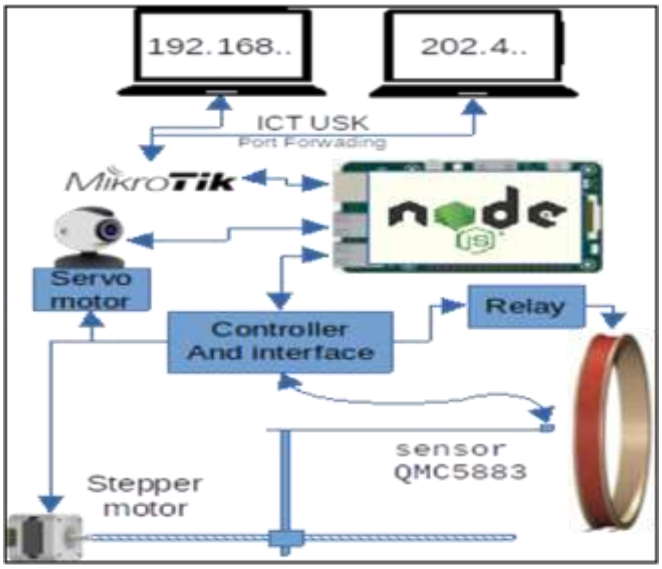

Figure 3. R-STEM block diagram of magnetic Induction by electric current

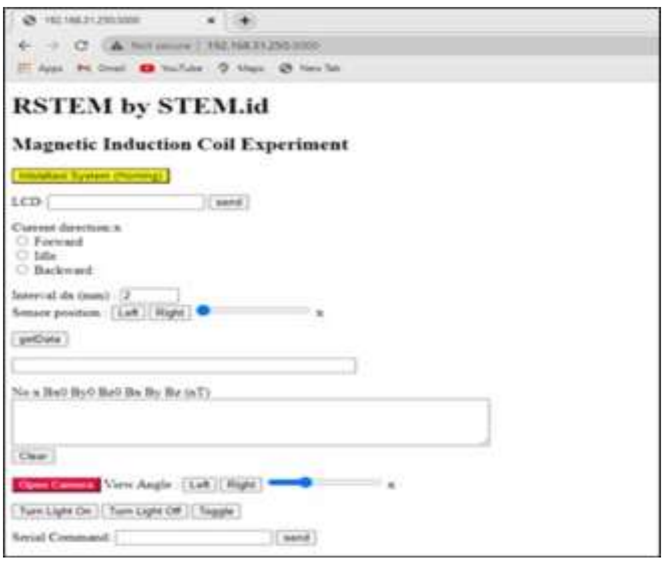

Figure 4. R-STEM platform for magnetic induction experiments

This device utilizes a JavaScript (JS) app to establish connections between the hardware, the internet, and HTML. Subsequently, it is linked to the index HTML for visual representation, as depicted in Figure 2, showcasing the physical form of the R-STEM device. Figure 3 displays the block diagram of the R-STEM device, and Figure 4 presents the user interface interaction.

Learning Activity Analysis

Learning activities commence with experiments to identify the nature of the magnetic field, magnetic induction on a straight wire, and magnetic induction on a solenoid. This experiment is carried out directly by students with learning media (experimental tools and materials) that have been provided. Then, the author conducts a review session with students regarding the physics concepts obtained from the experiments conducted before applying them to the topic of magnetic induction using the RSTEM Platform. RSTEM, as developed by Irwandi et al. (2021), has enhanced students' conceptual understanding and experimental skills by providing an interactive and flexible remote learning environment. This platform engages learners in physics experiments online, removing the limitations of physical facilities and improving cost efficiency in laboratory operations.

In utilizing the RSTEM Platform, it is expected that learners can plot magnetic induction data and explain the physical significance of the obtained graphs. Figure 5 and Figure 6 depict the results of magnetic induction graph plotting using the RSTEM Platform carried out by the learners during the learning process

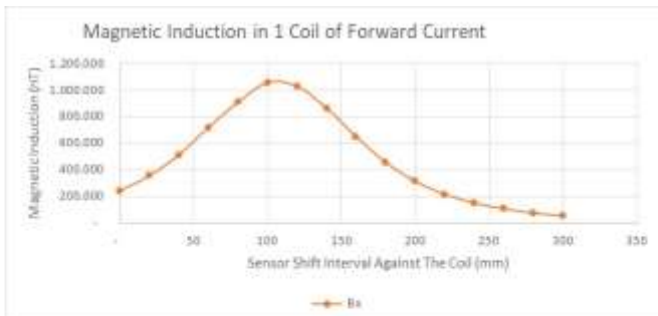

Figure 5. Curve of magnetic induction in a single coil with forward current

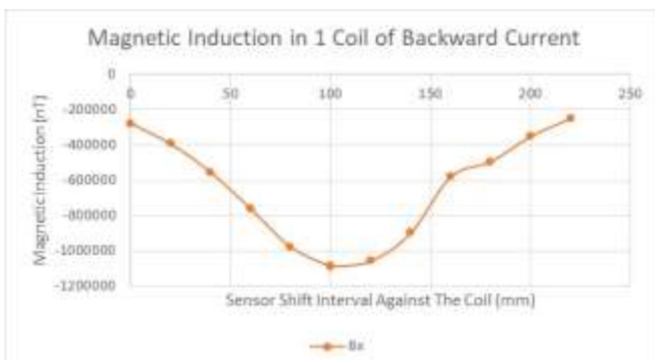

Figure 6. Curve of magnetic induction in a single coil with backward current

Bx graph is the magnetic induction value obtained experimentally using RSTEM. In this experiment, coil 1 is given a current in the "forward" direction. Next, the direction of the current is changed backward to produce a Bx graph as shown in Figure 6.

Regarding the Student Activity Sheets (LKPD) which is based on group-based learning, in this learning activity, the experimental results are also expressed on a carton that shows the 5C skills, the skills of creative thinking, critical thinking and problem-solving, communication, collaboration, and computational thinking. Figure 7 below is one of the results of students' creativity during the learning process.

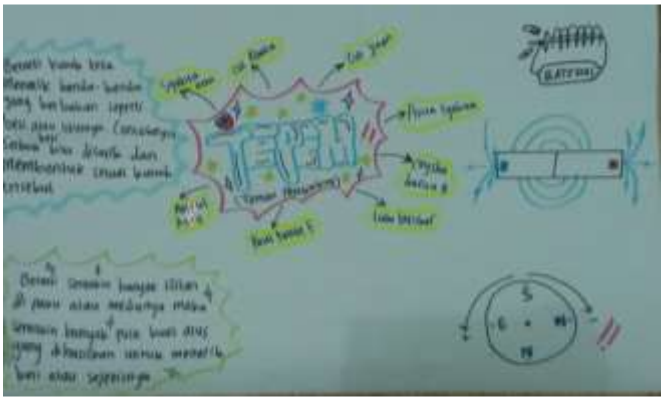

Figure 7. Creativity in the learning outcomes of the students during the learning process

Observation of learning activities is conducted to determine the implementation of the learning process that has been developed by ISLE Based STEM cycle, this observation was conducted by teachers of Unsyiah Laboratory High School, which are a math teacher, a biology teacher, and a physics alumni of PPG Prajabatan in 2022.

Learning Implementation Analysis

Observations on the implementation of learning were conducted by SMA Laboratorium Unsyiah teachers, including a mathematics teacher, a biology teacher, and a physics alumnus from the 2022 PPG Prajabatan program. The implementation achieved an overall score of 93%, with an average rating of 4.63 out of 5, categorizing it as 'excellent.' Three evaluated indicators contributed to this result: (1) the introduction phase obtained 91.7% with an average score of 4.58, the main activities reached 90.7% with an average score of 4.53, and the concluding activities achieved 95.5% with an average score of 4.78.

Improvement in Learning Outcomes

Assessment of increasing results using pretest and posttest. Even though the results of the pretest and posttest are not considered by students as a single standard of understanding the pretest and posttest results measure how effective the learning media designed in improving students' understanding of the topic of magnetic induction. Additionally, the learning materials are based on the ISLE-based STEM approach which is structured, which is structured based on a line of thinking that starts with basic concepts of physics. The results of the pretest and posttest carried out on students' learning activities are shown in Figure 8.

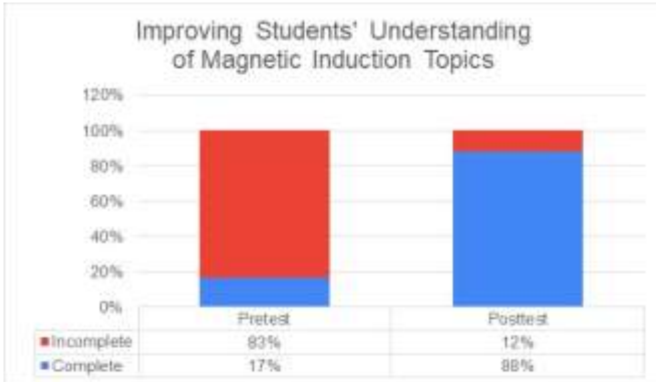

Figure 8. Improved student understanding of magnetic induction topics

Figure 8 presents data on the completeness of students participating in learning the topic of magnetic induction using distance learning media. The post-test results indicate that students' understanding of magnetic induction improved by 71% after participating in this learning process.

Student's Response to the Learning Process

Data on the results of the response of class X SMA Unsyiah Laboratory students to the ISLE-based STEM-based magnetic induction learning media are shown in Figure 9. Overall, the results of students' responses to the use of learning media with the ISLE-based STEM approach on the topic of magnetic induction using the RSTEM Platform fall into the Good category with a percentage value of 76%. The highest percentage is the magnetic induction aspect which is 80%.

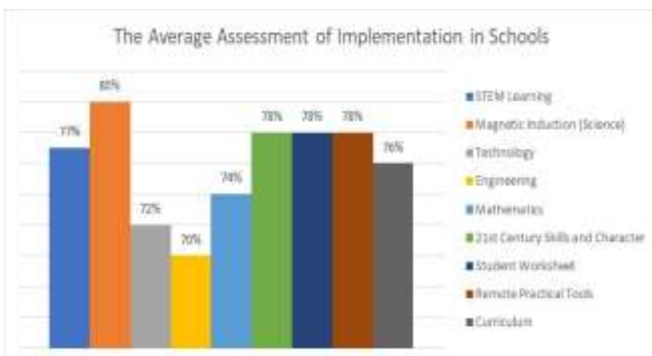

Figure 9. Average assessment of implementation in school using the RSTEM magnetic induction learning media

Conclusion

The R-STEM platform can be used as an educational tool for topics related to magnetic induction. This technology-based experiment can enhance students' understanding of magnetic induction material. The equipment's results, as evaluated by the teacher, fell into the good category with an average score of 3.9 out of a possible 5. ISLE-based STEM-based LKPD can be used as a medium in learning magnetic induction material. The results of the LKPD assessment by media experts obtained an average value of 4.2 assessed by the Labschool Unsyiah high school physics teacher into a very good category, getting a score of 3.6 assessed by material experts from a maximum scale of 5 and into a good category. The observer's evaluation of the application of learning using ISLE-based STEM media generated an average score of 4.63 out of 5 with the very good category, this shows that the process of teaching and learning activities using ISLE-based STEM learning media for magnetic induction material is very well implemented. In terms of how well learning is implemented utilizing STEM media based on ISLE, the observer gave it an average rating of 4.63 out of 5, which is considered very good. This shows that the process of teaching and learning activities using ISLE-based STEM learning media for magnetic induction material is very well implemented. According to the observer's evaluation of students' actions, the 'good' category received an average score of 3.93 across the nine characteristics evaluated. In student activity number four, three components had a low percentage of less than 75%. The significant increase of 71% in pretest and posttest results demonstrates the effectiveness of ISLE-based STEM learning materials in enhancing students' understanding of magnetic induction.

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Author Contributions

This research group played a crucial role in crafting this scientific paper, including generating ideas, designing the study, gathering and analyzing data, interpreting results, drafting the manuscript, writing the article, undergoing revisions, and securing funding for the research.

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Conflicts of Interest

The authors clarify that there is no conflict of interest.

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