Enhancing the Teaching and Learning Process of Faraday's and Lenz's Laws in Electromagnetic Induction using EM-Kit

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Abstract

Faraday's and Lenz's Laws are two central concepts in Electromagnetic Induction that appears challenging to students due to difficult terms in their definitions in absence of any hands-on experimental tool. EM-Kit, utilizing magnet, copper coil, PVC pipe, multiple LEDs, and oscillation ruler level, is therefore developed as active learning strategy to enhance the teaching and learning process of this topic. A two-cycled action research was conducted in collaboration of five physics lecturers in Kolej Matrikulasi Labuan (KML) towards three classes of sixty-seven students undertaking one-year matriculation program. Data was collected through observation, document analysis, and interviews with lecturers and students. Result showed that students are able to explain qualitatively the working principles of these concepts via physical tools, such as LED lighting and ruler oscillation. Students could also relate them to real-life electric generator and household AC current. In conclusion, the activity succeeded in encouraging students to learn actively by having them apply their understanding of Faraday's and Lenz's Laws through practical experience rather than just listening to lectures.

Keywords : *Action Research; Active Learning; Electromagnetic Induction; EM-Kit; Faraday's Law; Lenz's Law*

I. INTRODUCTION

A common disheartening question students often ask is, "Why am I learning this?" Students are unable to recognize the value of the subject matter or apply them in real-life settings. This question highlights the need for innovation in education that engages students and assists them to contextualize their learning swiftly. Hands-on pedagogies based on constructivism and active learning are the focus of a sustainable future education [1]. Based on teaching experience, Electromagnetic Induction is a major topic that is widely viewed as abstract and challenging for most students [2], [3].

Electromagnetic Induction is the production of induced emf whenever the magnetic flux through a loop, coil or circuit is changed. There are two central concepts in this topic, namely Faraday's Law and Lenz's Law. Faraday's Law states that the magnitude of induced emf is directly proportional to the rate of change of magnetic flux, as described by Equation 1:

$$\varepsilon_{ind} = -N\frac{d\phi}{dt} \quad \text{........ \textbf{Equations 1}}$$

Where:
ε_{ind} is the induced emf
N is the number of coil turns
$\frac{d\phi}{dt}$ is the rate of change of magnetic flux

The negative sign in the equation conveys the idea of Lenz's Law, which states that the induced current always flow in a direction that opposes the change in magnetic flux that causes it. Students are often confused about the definitions of these two laws, particularly the wording 'magnetic flux', 'change of magnetic flux', and 'oppose the change of magnetic flux' [2], [3], [4]. There is a lack of hands-on experimental tools in the laboratory to show how these two laws actually work. Therefore, this paper aims to enhance the students' visualization process of Faraday's and Lenz's Laws through hands-on experimental kit, namely the Electromagnetic Induction Kit (EM-Kit).

II. LITERATURE REVIEW

Active learning is considered as student-centred and focuses on construction of knowledge based on reflection and thinking [5]. In Physics, active

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learning encompasses any form of instruction that does not include traditional modes such as passive lecture or mathematical problem-solving [6]. It provides key opportunities for qualitative reasoning based on physics concepts, sense making of physics knowledge, engaging in the process of doing science, as well as application of knowledge across multiple contexts [6].

In the topic of Electromagnetic Induction, many new modern experimental tools had been developed as hands-on mediums to promote active learning among students. The all-time favourite demonstration of free-falling magnet in a conducting tube was further improved by changing the thickness of the tube wall, which subsequently changes the amount of eddy current induced and drop time of the falling magnet [7]. The magnetic moment and terminal velocity of this falling magnet were also determined when its dynamic was tracked by using sound wave generated by a smartphone and the acoustic resonance in the pipe was detected [8]. A past researcher also derived several formulas to calculate the induced current in a circular loop by an oscillating magnet to compare with measured values from experiment when exploring Faraday's Law [9].

A low-cost experiment without using any permanent magnet was also developed to investigate the Faraday's Law in a creative way [10]. The inexpensive microcontroller Arduino was also utilised to measure the magnetic moments and eddy currents, confirming Faraday's and Lenz's Laws [11]. Tracker, the popular video-based physics modelling tool, was also used to graph the dynamics of magnetically damped oscillations of a simple pendulum magnet due to eddy current induced over an aluminium sheet [12]. A powerful electronic system employing two blinking LEDs was also designed as a visual manifestation of Lenz's Law [13]. There was also research that concluded superconductors do not abide by Lenz's Law whereby the superconducting coil no longer responds to the change of external magnetic field [14].

III. REFLECTIONS ON PREVIOUS TEACHING

Based on observation, the researchers found that most of their students have trouble understanding Faraday's Law and Lenz's Law. Students typically displayed a lack of responsiveness to the queries posed by lecturers regarding these laws. The learning atmosphere in the classroom was gloomy when the lesson was conducted via verbal instruction only, and students' engagement was low. A focused group interview was conducted with several students regarding their understanding of these concepts. Students responded that they could not visualise their definitions and descriptions as stated in the lecture note. They could not explain these concepts in their own words, provide other examples, or relate with daily life applications. In order to test the students' understanding, a pre-test on the topic of Faraday's and Lenz's Laws was given to the students. Students' feedback on several conceptual questions was analysed and discussed.

Based on Figure 1, 19.4% of students had a misconception about Lenz's Law definition, which states that the induced current will flow in a direction such that the magnetic field produced by the induced current will always oppose the changing magnetic flux that produces the induced current. This problem arose due to some students confused about the term "oppose the change of magnetic flux". They regarded it as "oppose the magnetic flux", or in other words "repels the magnet", which is a wrong alternative conception. In reality, the magnetic flux induced can sometimes be in the same direction with the original magnetic flux. So it is not always "oppose the magnetic flux". This finding goes parallel with past research which also observed that students in their study had a common confusion where the induced field is "opposite in direction to the field which induces it", rather than "opposite in direction to the change in the field inducing it" [4]. The term "oppose the change" could be so easily misinterpreted as meaning "being in the opposite direction" [3].

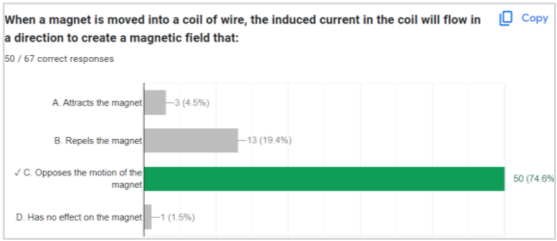

Figure 1. Students' feedback on question 1 regarding Lenz's Law.

Figure 2 also indicates that a considerable number of students (43.3%) were still unclear about how Lenz's Law works. They failed to find the actual direction of induced current as they did not understand how to apply Lenz's Law. This is also due to the term "oppose the change of magnetic flux" which confused most of the students.

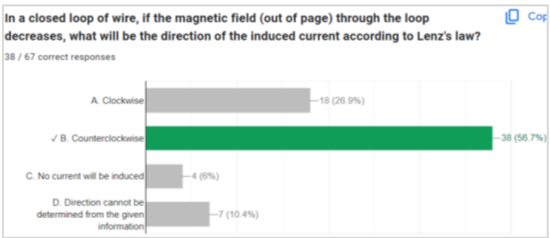

Figure 2. Students' feedback on question 2 regarding Lenz's Law.

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Figure 3 shows a lot of students (67.2%) had a misconception in Faraday's Law that induced current is produced due to the presence of magnetic flux. A focused group interview was conducted on these students to further assess their understanding on this matter. It was found that they had the wrong concept of induced current increasing when the magnet is moving closer to the coil, and induced current decreasing when the magnet is moving away from the coil. Even if the magnet is stationary right in between the coil, there is still induced current, and it will be at maximum value. This concept violates Faraday's Law of electromagnetic induction.

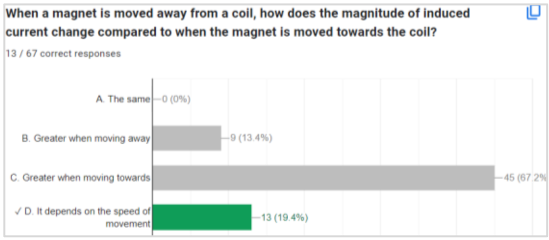

Figure 3. Students' feedback on question regarding Faraday's Law.

According to Faraday's Law, the current is not induced due to the presence of magnetic flux but is induced due to the change in magnetic flux. This means that the current is only induced when there is a relative motion between the coil and magnet. Therefore, induced current only increases if the magnet is moving faster and decreases if the magnet is moving slower. Magnet moving towards or moving away from coil only changes the direction of induced current but not the magnitude of induced current. Induced current is not increasing due to the presence of stronger magnetic flux but is due to faster change in magnetic flux when there is a larger relative movement between coil and magnet.

Figure 4 hinted that a fairly large (23.9%) number of students did not realise that the induced current is a type of alternating current (AC). They thought that it is direct current (DC) instead. The students are unable to relate the concepts in electromagnetic induction to real-life situations, such as how the electric generator in a power plant generates electricity. Therefore, this project is a good example to showcase physically for students how AC is generated when the magnet is oscillating through the coil.

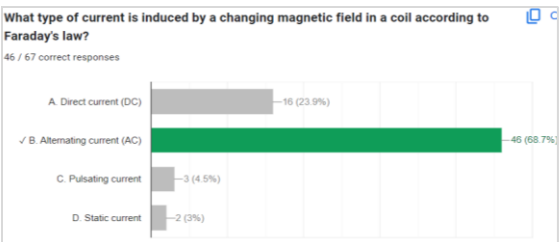

Figure 4. Students' feedback on question regarding application of Faraday's and Lenz's Laws.

In a nutshell, a lot of students seemed to have misconceptions about Faraday's Law and Lenz's Law. First, they thought that emf is induced due to the presence of magnetic flux but not the change in magnetic flux. Secondly, they were also confused about the term "oppose the change of magnetic flux" in Lenz's Law definition but considered it as "oppose the magnetic flux." These confusion and misunderstanding were largely due to lack of physical demonstration of these two laws themselves. Students learned these concepts only through lecture notes and verbal explanations by the lecturers. In the laboratory setting, there are no physical lab tools for students to experiment with these laws hands-on. It is also very difficult for lecturers to explain these laws verbally without physical teaching tools.

IV. STUDY FOCUS

The main objective of this study is to improve the teaching and learning process on the topic of Electromagnetic Induction. The specific objective is by the end of the lesson, students are able to explain qualitatively the working principles of Faraday's Law and Lenz's Law using the EM-Kit, instead of just stating their definitions in words. The other specific objective is students can even relate these laws into real-life situations. The research was conducted with one-year matriculation program students from Kolej Matrikulasi Labuan (KML) during their second semester of Physics subject (SP025). Three different classes of sixty-seven students taught by the researchers had been selected to implement the activity because the intervention was repeated and improved for two consecutive cycles.

Table 1. Target group composition.

Cycle	Practicum	Gender		Total
		Male	**Female**	
1	F13	9	13	22
2	F14 & F15	16	29	45
	Total	25	42	67

V. RESEARCH METHODOLOGY

A. Research Design

The research was implemented in the Action Research model which comprises of four stages: observe, plan, implement, and reflect for the following cycles [15]. Data was collected through observation, document analysis, and interviews with lecturers and students. Lesson worksheet documents, documents of students' work, questionnaire survey data, audio recordings of interviews, observation photos and video recordings

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during the intervention were also gathered. All these data significantly contribute to the narrative analysis [16]. Besides, the self-evaluation process can be enhanced within a community of critical friends. Therefore, the head of the physics unit, the subject matter expert (SME), and another two senior lecturers were invited to act as critical friends for the action research. The action research had been carried out for two consecutive cycles, incorporating any revisions between cycles.

B. Intervention

The EM-Kit consists of two separate projects which are adopted and adapted from past research [17], [18]. Figure 5 shows the experimental setup for the first project. This project aims to showcase the effect of Faraday and Lenz's Laws physically through the lighting of LEDs when a magnet slides through a copper coil. The copper coil is made of enamelled copper wire with thickness 0.35 mm and has 400 turns. The big magnet consists of five super strong neodymium magnets, each with diameter 20 mm and thickness 10 mm. The small magnet consists of ten neodymium magnets, each with diameter 10 mm and thickness 3 mm. A long white PVC pipe is used to wind the 400-turn copper coil and to allow the sliding of magnet through the pipe. Two green and red LEDs are soldered and connected to the copper coil in such a way that to investigate the direction of induced current flow in the copper coil. These dual-directional LEDs function almost the same as the center zero galvanometer.

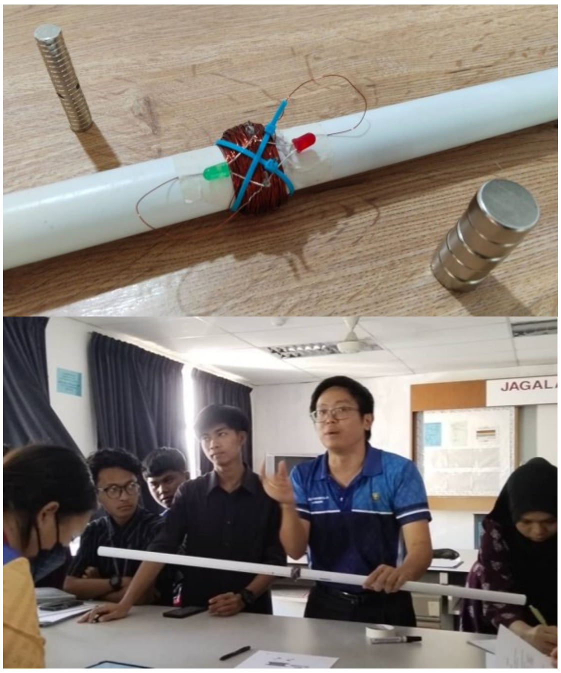

Figure 5. Experimental setup for first project of EM-Kit.

First, this project can show the relationship between strength or speed of moving magnet and magnitude of induced emf in order to understand Faraday's Law. When a magnet is let to slide through the pipe and the copper coil, the LEDs will light up. The LEDs only light up when the magnet is sliding, but do not light up if the magnet is stationary inside the copper coil. Students can compare the brightness of LEDs between using small and big magnets to slide through the copper coil. A long PVC pipe is also used to allow students to control the speed of the sliding magnet, so they can relate how the speed affects the brightness of the LEDs. These observations are important for students to understand how Faraday's Law works.

Secondly, before beginning the experiment, students are requested to guess which LED will light up if they slide down the magnet through the copper coil. They have to determine the directions of induced current through the coil when the magnet is approaching or moving away based on Lenz's Law and Right-Hand-Grip-Rule. When students slide a magnet through the copper coil, they will observe that the LEDs will only light up one after another but not simultaneously. They will notice that the red LED lights up first followed by the green LED, or vice versa. Then, students need to invert the pole of the magnet and let it slide through the copper coil again. This time they will notice that the sequence of which LED lighted up first is also inverted. This activity is a good exercise for students to apply Lenz's Law hands-on.

Figure 6 shows the experimental setup for the second project. This project aims to showcase the effect of Faraday and Lenz's Laws physically through oscillation movement of coils when a magnet is approaching or moving away from it. It allows students to 'feel' the attractive or repulsive force in their hands while pushing in or pulling out the magnet from the coil due to electromagnetic induction. Three copper coils were made, namely (1) 200-turn open coil, (2) 200-turn closed coil, and (3) 500-turn closed coil. A long metre-rule was used as a level. Two activities had been designed for this project. The first activity requires the students to prove the existence of induced emf based on Faraday's Law. Students need to place both of 200-

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turn copper coils at both ends of the ruler to balance, closed coil at one end, and open coil at the other end. Then, students will use the magnet to test sliding in and out both coils and observe which coil reacts to the magnet.

Figure 6. Experimental setup for second project of EM-Kit.

The second activity is students need to test the difference between 200-turn and 500-turn copper coils against the amplitude of level oscillation. This activity will let students verify the relationship between number of coil turns and magnitude of induced emf in order to understand Faraday's Law. Besides, students will also pay attention to the direction of ruler movement when the magnet is approaching the coil or moving away from the coil, as this will also showcase the working principle of Lenz’s Law. Both projects with LEDs and level balance were administered in a tutorial class by Mr Pek for the first cycle, under close observation by the team members who acted as the observers, as shown in Figure 7(a). Figure 7(b) shows the group photo with students involved in the project, whereas Figure 7(c) shows all five lecturers as the researchers of this project.

(a)

(b)

(c)

Figure 7. Classroom activities: (a) EM-Kit activities under closed observation by other lecturers, (b) group photo with students, (c) the researchers.

VI. RESULT AND DISCUSSION

A. First Cycle

Figure 8 shows a survey that was distributed among students using Google Form to collect their feedback regarding the things they learnt from the projects. Through hands-on physical experiment, students claimed that they could clearly see the relationship between the speed or size of a bar magnet with the magnitude of induced current, which is portrayed by the brightness of LEDs when lighted up. They could visualize the Faraday’s and Lenz’s Laws in a more physical way as well as relating it with daily life examples. A further interview with the students revealed that they could visualize that this EM-Kit mimics the power plant that generates electricity. Two primary components, such as magnet and copper coil, always can be found in an electric generator. Similar to this experiment, AC current is always generated for household consumption.

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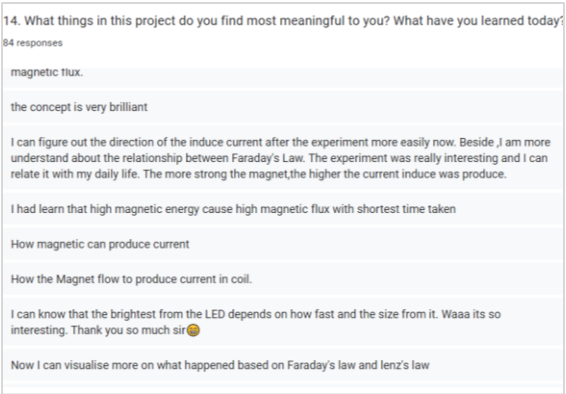
14. What things in this project do you find most meaningful to you? What have you learned today?
84 responses

magnetic flux.

the concept is very brilliant

I can figure out the direction of the induce current after the experiment more easily now. Beside ,I am more understand about the relationship between Faraday's Law. The experiment was really interesting and I can relate it with my daily life. The more strong the magnet,the higher the current induce was produce.

I had learn that high magnetic energy cause high magnetic flux with shortest time taken

How magnetic can produce current

How the Magnet flow to produce current in coil.

I can know that the brightest from the LED depends on how fast and the size from it. Waaa its so interesting. Thank you so much sir😂

Now I can visualise more on what happened based on Faraday's law and lenz's law

Figure 8. Students' feedback in questionnaire regarding the EM-Kit activities.

However, their description towards Faraday's and Lenz's Law still remained vague based on their responses. They did not provide accurate terms such as 'change of magnetic flux' that induced the current. Instead, students mentioned 'magnetic' or 'magnet flow' that produced the current, which were inaccurate definitions. The students could visualise physically how Faraday's Law works in the project but still unable to clearly explain its definition in correct terms. "Large induced emf caused by large change in magnetic flux" in Faraday's Law was wrongly described as "high magnetic energy caused by high magnetic flux". It is important to note that "large change in magnetic flux" has a totally different meaning compared to "large magnetic flux".

In order to fix their vague understanding towards the real concepts of Faraday's and Lenz's Law, the researchers proposed that a guided worksheet should be provided alongside the kit to help explain the working principles of these laws in accurate terms related to this project. Thus, the team collectively designed the worksheet which included students' observational data table and explanation according to the physical laws as well as equations. To lessen the cognitive load, the worksheet employs a fill-in-the-blank method to keep the students on track with the concepts easily. The whole project incorporating the revision was re-conducted again on another two tutorial classes for the second cycle. Figure 9 shows the usage of a worksheet during the second cycle to guide the Right-Hand-Grip-Rule lesson when determining the direction of induced current.

Figure 9. A guided worksheet alongside EM-Kit.

B. Second Cycle

Figure 10 shows sample data from the students' worksheet, where it is proven that students can explain qualitatively the working principle of Faraday's Law in both projects using Faraday's equation. In the first project as shown in Figure 10(a), the induced emf as represented by the brightness of LED is proportional to the rate of change of magnetic flux. Students noticed that the LED was dimly lit when the magnet slid through the coil slowly, whereas the LED was brightly lit when the magnet slid through the coil at a fast speed. They arrived at a conclusion that the higher the speed of magnet, the shorter the time taken (t) for change of magnetic flux, thus the higher the magnitude of induced emf. This shows that this project is able to assist students in visualizing the induced emf physically through the brightness of LED.

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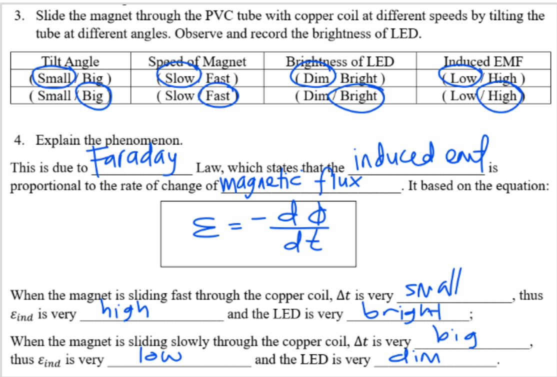

3. Slide the magnet through the PVC tube with copper coil at different speeds by tilting the tube at different angles. Observe and record the brightness of LED.

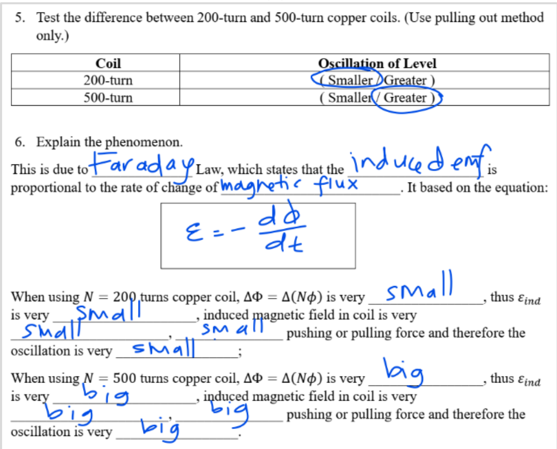
Tilt Angle	Speed of Magnet	Brightness of LED	Induced EMF
(Small / Big)	(Slow / Fast)	(Dim / Bright)	(Low / High)
(Small / Big)	(Slow / Fast)	(Dim / Bright)	(Low / High)

4. Explain the phenomenon.
This is due to Faraday Law, which states that the induced emf is proportional to the rate of change of magnetic flux. It based on the equation:

$$\varepsilon = -\frac{d\phi}{dt}$$

When the magnet is sliding fast through the copper coil, Δt is very small, thus ε_{ind} is very high and the LED is very bright;
When the magnet is sliding slowly through the copper coil, Δt is very big, thus ε_{ind} is very low and the LED is very dim.

(a)


5. Test the difference between 200-turn and 500-turn copper coils. (Use pulling out method only.)

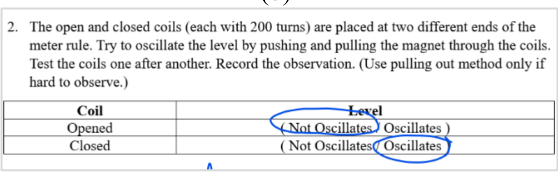
Coil	Oscillation of Level
200-turn	(Smaller / Greater)
500-turn	(Smaller / Greater)

6. Explain the phenomenon.
This is due to Faraday Law, which states that the induced emf is proportional to the rate of change of magnetic flux. It based on the equation:

$$\varepsilon = -\frac{d\phi}{dt}$$

When using $N = 200$ turns copper coil, $\Delta\Phi = \Delta(N\phi)$ is very small, thus ε_{ind} is very small, induced magnetic field in coil is very small, small pushing or pulling force and therefore the oscillation is very small;
When using $N = 500$ turns copper coil, $\Delta\Phi = \Delta(N\phi)$ is very big, thus ε_{ind} is very big, induced magnetic field in coil is very big, big pushing or pulling force and therefore the oscillation is very big.

(b)


2. The open and closed coils (each with 200 turns) are placed at two different ends of the meter rule. Try to oscillate the level by pushing and pulling the magnet through the coils. Test the coils one after another. Record the observation. (Use pulling out method only if hard to observe.)

Coil	Level
Opened	(Not Oscillates / Oscillates)
Closed	(Not Oscillates / Oscillates)

(c)

Figure 10. Students' worksheet regarding Faraday's Law: (a) first project, (b) and (c) second project.

In the second project as shown in Figure 10(b), the induced emf is represented by the amplitude of oscillation of the ruler level. Students noticed a smaller amplitude of oscillation when using a coil with lesser turns (200), whereas the oscillation became larger when using a coil with more turns (500). They learnt that the higher the number of turns, the more the magnetic flux changes, thus the higher the magnitude of induced emf. Thus, the kit is able to help students visualize the induced emf too through amplitude of ruler oscillation.

In Figure 10(c), students could also notice that only the closed coil reacted to the moving magnet and oscillated. The opened coil did not oscillate at all. The usage between opened and closed coils here clearly proves the existence of induced current that only flows in a closed coil. A further interview with the students revealed that they understood there was a current induced in the closed coil, which caused it to react towards the magnet. No current can be induced in an opened coil. The induced current was due to Faraday's Law, which states that an emf will be induced whenever there is a change of magnetic flux through a closed coil.

In Figure 11, students have proven that they are able to explain qualitatively the working principle of Lenz's Law in the first project involving LEDs by determining the correct directions of the induced magnetic field in the solenoid when sliding a magnet across it to and fro. Based on the law, the copper coil tends to oppose the motion of a moving magnet by 'repelling' it when the magnet is approaching, or 'attracting' it when the magnet is moving away. The copper coil thus generates induced emf or current to produce the corresponding magnetic fields for the repel or attract effect. Students were also able to use Right-Hand-Grip-Rule (RHGR) in determining the direction of induced-current in the circuit. Since the LED only allows uni-direction of induced current flow, they could see that the red and green LEDs only get lighted up by induced current one after another but not simultaneously. In the reverse slide, they also observed that sequence of which LED gets lighted up first follows the sequence during initial slide. Finally, they arrived at a conclusion that when the magnet is oscillating through the solenoid, an alternating current (AC) is generated in the circuit. This is due to the repeating lighting sequence of either Red-Green-Red-Green or Green-Red-Green-Red LEDs during initial and reverse slide. This situation clearly explains why the electric generator in any electric station generates AC current but not DC current for our household utility. Based on the answer provided by students in Figure 5, it clearly shows that students can relate this concept to real-life situations such as the electric generator which generates AC current.

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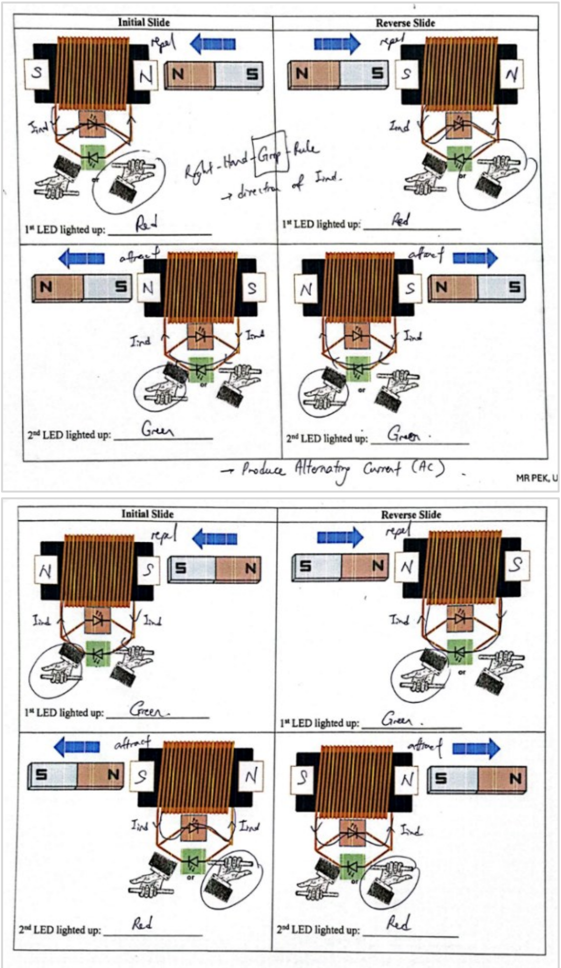
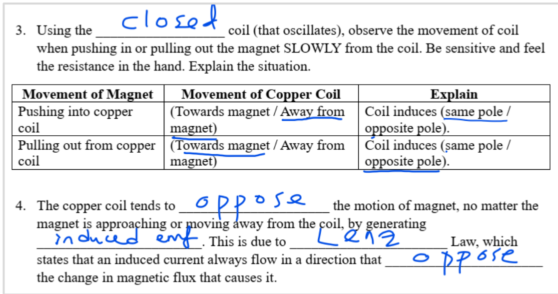


Figure 11. Students' worksheet regarding Lenz's Law in first project.

Figure 12 shows that students could explain qualitatively the working principle of Lenz's Law too in the second project. Here, instead of showing the direction of induced current flow by LEDs, the project actually allows a direct observation of the "repel or attract" effect as stated in Lenz's Law through the oscillation movement of copper coil on a level. They could "feel and watch" physically that the copper coil was being repelled when they pushed a magnet into it. They also noticed that the copper coil was attracted to the magnet when the magnet was pulled out from the copper coil. It was as though an invisible force pushing or pulling the copper coil although the magnet was not in contact with it. Students were able to provide an explanation of the situation using Lenz's Law that the copper coil tends to oppose the motion of a magnet by generating induced emf.



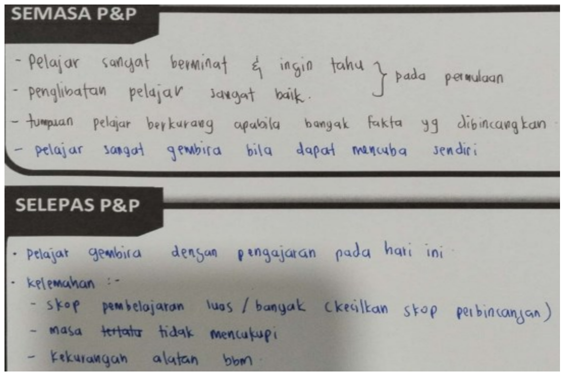
3. Using the closed coil (that oscillates), observe the movement of coil when pushing in or pulling out the magnet SLOWLY from the coil. Be sensitive and feel the resistance in the hand. Explain the situation.

Movement of Magnet	Movement of Copper Coil	Explain
Pushing into copper coil	(Towards magnet / Away from magnet)	Coil induces (same pole / opposite pole).
Pulling out from copper coil	(Towards magnet / Away from magnet)	Coil induces (same pole / opposite pole).

4. The copper coil tends to oppose the motion of magnet, no matter the magnet is approaching or moving away from the coil, by generating induced emf. This is due to Lenz Law, which states that an induced current always flow in a direction that oppose the change in magnetic flux that causes it.

Figure 12. Students' worksheet regarding Lenz's Law in second project.

Figure 13 shows lecturers' feedback towards the EM-Kit activities. The team members who acted as observers shares a similar view that students were very interested and had high curiosity as they could try the experiment hands-on. They gave active responses and engagement. However, some students seemed to be distracted when too many concepts were taught and linked at the same time. Students, in particular, were unable to visualize some abstract concepts such as the "change of magnetic flux", despite the fact that the effect can be observed in LED lights. Besides, there was also only a limited set of EM-Kit available, and most students had to wait for their turn to try it. Therefore, the team suggested that a supporting PhET simulation can be provided to help students visualize the concepts better. Perhaps a gallery walk should be implemented with a station conducting the physical experiment using EM-Kit, whereas the other station offers students the PhET simulation to be manipulated.



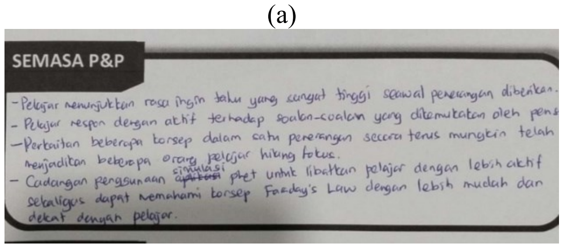
SEMASA P&P

- Pelajar sangat berminat & ingin tahu } pada permulaan
- penglibatan pelajar sangat baik. }
- tumpuan pelajar berkurang apabila banyak fakta yg dibincangkan
- pelajar sangat gembira bila dapat mencuba sendiri

SELEPAS P&P

- Pelajar gembira dengan pengajaran pada hari ini
- kelemahan :-
  - skop pembelajaran luas / banyak (kecilkan skop perbincangan)
  - masa ~~tertatur~~ tidak mencukupi
  - kekurangan alatan bbm

(a)



SEMASA P&P

- Pelajar menunjukkan rasa ingin tahu yang sangat tinggi seawal penerangan diberikan.
- Pelajar respon dengan aktif terhadap soalan-soalan yang dikemukakan oleh pens
- Perkaitan beberapa konsep dalam satu penerangan secara terus mungkin telah menjadikan beberapa orang pelajar hilang fokus.
- Cadangan penggunaan ~~aplikasi~~ simulasi phet untuk libatkan pelajar dengan lebih aktif dengan lebih mudah dan sekaligus dapat memahami konsep Faraday's Law dengan lebih mudah dan dekat dengan pelajar.

(b)

Figure 13. Lecturers' feedback in both projects: (a) Lecturer 1, (b) Lecturer 2.

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In Figure 14, the PhET simulation clearly shows the abstract concept such as the change of magnetic flux in the copper coil that induces the emf. It provides visual representations to show the invisible, such as the magnetic field lines [19]. Multiple audio-visual representations are provided to support deeper understanding and build real-world connections [19]. For instance, there is a voltmeter to show the change in induced current direction when the magnet bar moves in and out of the copper coil. A supporting background sound also accompanies the animation to help identify the change in induced current direction as the magnet bar slides through the copper coil. Learning physics is fun, real, and simple through PhET interactive simulation [20]. It also proved to significantly improve the academic performance of students in Science [21].

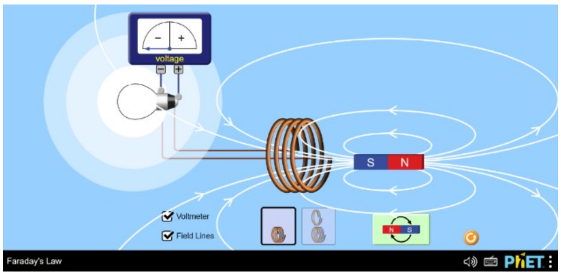

Figure 14. PhET simulation regarding Faraday's and Lenz's Laws [22].

In short, this simulation fully supplements the visualization process of Faraday's Law and Lenz's Law for the physical experiment conducted by students. It assists in explaining the abstract concept of magnetic flux that is otherwise invisible in a physical experiment. Following much debate, the team arrived at an integrated approach that includes the EM-Kit, guided worksheet, PhET simulation, and gallery walk, which can be applied during the future third cycle.

The electromagnetic induction kit was introduced to the Physics Unit KML among fellow lecturers during the Physics Sharing Session (PSS). Videos recorded during the classroom activity with students were showed and commented by lecturers. The Head of Physics Unit who acted as a critical friend had remarked that the activity was interesting and able to explain the concepts of Faraday's and Lenz's Laws to students. However, some lecturers responded that while these activities may aid in conceptual understanding, they are ineffective in problem solving involving formula calculations. The activities are more suitable to be conducted during lab sessions with longer hours. Instruction and explanation from lecturers are still much needed to guide students to understand the underlying principles behind the project as there are a lot of concepts involved. The sharing process has spurred interest in other physics teachers to develop comparable initiatives for their own classes. Lecturers also suggested that such activity be demonstrated during Physics Open Day (POD). Most importantly, the action research has undoubtedly boosted lecturers' collaborative efforts to benefit a larger pool of students. The author of this work also hopes to have it published in a journal to help other scholars.

VII. CONCLUSION

Generally, the objectives had been achieved where students are able to explain qualitatively the working principles of Faraday's and Lenz's Laws using EM-Kit, instead of just stating their definitions. In students' worksheet, they could draw a relationship between strength or speed of sliding magnet and magnitude of induced emf which correspond to the brightness of LEDs. Students can also explain how the amount of coil turns affects the amplitude of level oscillation. The necessity of using a closed coil instead of opened coil further convinced the students about the existence of induced current in the closed coil. The direction of induced current can also be determined correctly by students when they investigate the sequence of which LED gets lighted using Lenz's Law. Students also used Lenz's Law appropriately to explain the direction of sea-saw ruler oscillations. Finally, students can relate these two laws in real-life situations when they learnt that magnet and copper coil are primary components in any electric generators as well as the usage of household AC supply.

However, the problem of lacking several experimental sets and difficulty in visualizing abstract subjects such as magnetic flux still persist. Therefore, the suggestion for improvement in the third cycle will be conducting a gallery walk that comprises two stations: one with experimental set while the other with PhET Simulation that helps with the visualization process of the experiment. It is noteworthy that the activity encourages students to learn actively by having them apply their understanding of Faraday's and Lenz's Laws through practical experience rather than listening to lectures. The team found that, despite the study being in its second cycle, the project is on the right track towards a sustainable future education. In addition to imparting knowledge, educators must instill in their students a sense of purpose in their knowledge they learnt so as to be valued by them [1].

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REFERENCES

[1] S. Sarma and A. Bagiati, "Current innovation in STEM education and equity needs for the future.," in Symposium on Imagining the Future of Undergraduate STEM education, 2021.

[2] D. S. Richards, A case study of students' conceptions on electromagnetic induction while viewing a series of videos, animations, and interactive simulations., etda.libraries.psu.edu, 2010.

[3] C. Raduta, "General students' misconceptions related to Electricity and Magnetism.," 2005.

[4] W. M. Thong and R. Gunstone, "Some student conceptions of electromagnetic induction.," Research in Science Education, vol. 38, pp. 31-44, 2008.

[5] S. Hartikainen, H. Rintala, L. Pylväs and P. Nokelainen, "The concept of active learning and the measurement of learning outcomes: A review of research in engineering higher education.," Education Sciences, vol. 9, no. 4, p. 276, 2019.

[6] D. Lombardi, T. F. Shipley, A. T. B. T. C. T. E. T. G. T. G. T. and P. T. , "The curious construct of active learning.," Psychological Science in the Public Interest, vol. 22, no. 1, pp. 8-43, 2021.

[7] R. Hobbs, "Adding a New Layer to a Favorite Demonstration: The Falling Magnet in a Conducting Tube.," The Physics Teacher, vol. 61, no. 9, pp. 727-730, 2023.

[8] S. K. Pal, S. Sarkar and P. Panchadhyayee, "Determination of the magnetic moment of a magnet by letting it fall through a conducting pipe.," Physics Education, vol. 59, no. 1, p. 015022, 27 November 2023.

[9] H. J. Ha, T. Jang and S. H. Sohn, "Currents induced in a circular loop by an oscillating magnet.," Physics Education, vol. 57, no. 6, p. 065013, 9 September 2022.

[10] D. T. M. Fontes and A. M. Rodrigues, "Faraday's Law Low-Cost Experiment Without Permanent Magnets.," The Physics Teacher, vol. 59, no. 5, pp. 345-347, 2021.

[11] D. V. Gadre, H. Sharma, S. D. Gadre and S. Srivastava, "Science on a stick: An experimental and demonstration platform for learning several physical principles.," American Journal of Physics, vol. 91, no. 2, pp. 116-121, 2023.

[12] U. B. Pili, "Modeling damped oscillations of a simple pendulum due to magnetic braking.," Physics Education, vol. 55, no. 3, p. 035025, 1 April 2020.

[13] J. T. d. Moraes, B. F. Rizzuti and B. Gonçalves, "Instructional experiment on Lenz's law.," Quarks: Brazilian Electronic Journal of Physics, Chemistry and Materials Science, vol. 4, pp. 61-80, 2022.

[14] Y. Xin, W. Li, Q. Dong, T. Yang, B. Tian and Q. Li, "Superconductors and Lenz's law.," Superconductor Science and Technology, vol. 33, no. 5, p. 055004, 19 March 2020.

[15] S. Kemmis and R. McTaggart, The Action Research Planner, 3rd ed., Waurn Ponds: Deakin University Press, 1988.

[16] M. Jean and W. Jack, Action Research: Principles and Practice, British: Taylor and FrancisGroup, 2002.

[17] F. Behroozi, "Electromagnetic Induction and Lenz's Law Revisited," The Physics Teacher, vol. 57, no. 2, pp. 102-104, February 2019.

[18] R. Hessel, "More on Faraday's and Lenz's laws - Qualitative demonstrations.," The Physics Teacher, vol. 49, no. 3, pp. 184-185, March 2011.

[19] C. E. Wieman, W. K. Adams and K. K. Perkins, "PhET: Simulations that enhance learning.," vol. 322, no. 5902, pp. 682-683, 31 October 2008.

[20] C. T. Batuyong and V. V. Antonio, "Exploring the effect of PhET® interactive simulation-based activities on students' performance and learning experiences in electromagnetism.," Asia Pacific Journal of Multidisciplinary Research, vol. 6, no. 2, pp. 121-131, 2018.

[21] R. L. Mallari and G. D. Lumanog, "The effectiveness of integrating PhET interactive simulation-based activities in improving the student's academic performance in science.," International

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Accepted: 25 June 2024
Publisher: ICBE Publication

Journal for Research in Applied Science and Engineering Technology, vol. 8, no. 9, pp. 1150-1153, September 2020.

[22] PhET University of Colorado, "Faraday's Law," PhET University of Colorado, 2024. [Online]. Available: https://phet.colorado.edu/en/simulations/faradays-law.

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