Teaching and Learning about Magnetic field and Electromagnetic Induction Phenomena integrated Science, Technology, Engineering and Mathematics (STEM) Education in Vietnamese high schools

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Abstract. This work presents the study on teaching and learning about magnetic and electromagnetic induction phenomena integrated science, technology, engineering and mathematics (STEM) education in Vietnamese high schools for addressing issues of relevance and epistemic practice. We have explored STEM education with the creative and experiential activity in magnetic and electromagnetic induction phenomena. The STEM experiments and technical toys about magnetic and electromagnetic induction phenomena have been designed to be applied for active learning for students. The integration of STEM education will increase motivation and achievement in physics subjects and enhance capacity to improve student learning.

1. Introduction

STEM stands for Science, Technology, Engineering, and Math. STEM education is essentially meant to equip learners with the necessary knowledge and skills in the areas of science, technology, engineering and math. Teaching STEM has helped to "flatten" the global economy in the 21st century. STEM education has evolved into a meta-discipline, an integrated effort that removes traditional barriers between these subjects, and instead focuses on innovation and the process of applying design solutions to complex context issues using existing tools and technologies [5]. STEM education projects and plans have been developed all around the world. The US has launched the STEM education strategic plan that was used multiple strategies to make progress on improving STEM education including: Making STEM a priority in more of the Administration’s education efforts, getting ambitious but achievable goals and challenging the private sector, and even Capitalizing on the President’s deep interest and leadership [4]. There is even a project to enhance the access of female students to STEM by developing a bridging program for female students at the University of Malawi (Africa) [8]. The survey of IRIS project (Interests and Recruitment in Science; http://iris.fp-7.org/about-iris/) in Austria and Germany has reported that the STEM studies choice and preference of first-year students depend on high school experience and good teachers [3].

STEM education activities show that STEM education applies a learning approach based on practice and experiential activities. The most progressive, flexible educational methods such as
project-based learning, learning through the games, and especially learning through practice are fully applied STEM integrated subjects. Students who follow the STEM approach have outstanding advantages such as: firm knowledge of science, technology, engineering, and mathematical; creativity, logical thinking, excellent performance in learning and working. Also, they have the opportunity to develop soft skills more comprehensively while not feeling overloaded [1-7]. For high school students, taking STEM courses also has a positive effect on future career choices. When learning a variety of knowledge in an integrated way, students will actively enjoy their learning rather than being afraid of or avoiding a certain area. This will, thereby, encourage them to have a better orientation when choosing majors for higher education and certainty for future careers.

To date in Vietnam, STEM education is not just studied and developed in universities but has been already progressed in high schools [9]. Research on STEM education has been carried out in the Faculty of Physics, Thai Nguyen University of Education. First of all, STEM education is developed to teach students how to apply STEM teaching in high schools [7]. Physics lessons will be interesting, engaging, and help students understand better if teaching is linked to visualizations and active learning. The skills and knowledge in the areas of science, technology, engineering and math (called STEM skills) must be integrated, complemented with each other to help students not only understand the principles but also be able to apply them in practice and create products in daily life. Compared with natural sciences, physics is a subject that is closely related to mathematical, technological, technical and scientific contents, so STEM-oriented education in teaching Physics has a very favorable condition. STEM education is aimed at developing following specific capabilities of each subject for students:

i. Critical thinking and problem solving skills
ii. Communication and collaboration skills
iii. Creativity and discovery skills
iv. Culture, information and communications technology
v. Ability to perform project-base tasks
vi. Presentation capacity

In this work, we designed the process of teaching some STEM-oriented contents of “Magnetic field” in Physics Grade 11 in order to enhance the activeness, train skills and develop capabilities for students

2. Methodology

2.1. The process of teaching physics under STEM education

STEM education applies practice-based and experiential approaches; therefore, when following STEM method, students will be able to use materials to generate products that will enable them to develop their competences in science, engineering, technology and mathematics to acquire knowledge. Through studying the theory of active teaching, and STEM teaching, we have proposed a process of teaching physics related to STEM education which includes the stages showed in figure 1.

The stages of teaching physics integrated STEM are described in detail following steps:

Stage 1: Select STEM topics

STEM topics in teaching are issues associated with the designing and manufacturing of products related to high school physics knowledge. STEM topics should have a close relationship with reality, solving practical problems, serving the daily life or entertainment of learners.

Stage 2: Define STEM tasks

Based on the STEM topics, students are asked to identify STEM tasks that need to be addressed

Stage 3: Study STEM documents and materials

After receiving STEM assignments, students study STEM documents so that they can clearly identify the ideas and methods of generate outcomes as well as learn about the contents of relevant physics knowledge in from the STEM topics.
Figure 1. Procedure of the teaching process under STEM education.

Stage 4: Generate STEM outcomes
- Divide classes into groups
- Groups actively assign specific tasks to each member of the group according to their capacity
- Investigate the tools and materials distributed
- Generate STEM outcomes
  This is a difficult step so teachers need to keep track of the activities of each group and give timely help and guidance if necessary. On the other hand, product manufacturing also requires students to meet safety rules so teachers should prepare safety rules and disseminate them to learners. Some complex details may need processing, and then teacher can help learners in this process.

Stage 5: Test the outcomes
  During this phase, there are two possibilities for the groups that test the outcomes to access the relevant knowledge of the topic: (1) If the product has defects in its manufacturing process or not consistent with the given knowledge, those groups should review the STEM documents to further refine the product; (2) If the product meets the requirements, those groups will use it to collect the results, make conclusions on the knowledge of magnetic field.

Stage 6: Report experimental results
  Groups report the results obtained in stage 5 in form of tables, graphs or qualitative conclusions.

Stage 7: Comments and discussion
Groups review and evaluate products of other groups in the form of peer review. Then, teacher evaluates and gives comments and discussion. Students are encouraged to review the teacher's assessments.

**Stage 8: Conclusion**

Teacher makes conclusions about the tasks achieved, the knowledge students have acquired, the positive and limited aspects in the teaching process. In addition, teacher gives rewards to members, groups with good sense of learning, good learning results, reminding and giving advises to individuals and groups who do not have good results.

### 2.2. Analyze the knowledge of the section “Magnetic field - electromagnetic induction phenomenon” under STEM education

After studying the magnetic field - Electromagnetic induction phenomenon - and the facilities (experiments) are equipped, a number of appropriate content is selected to teach under STEM education including the magnetic field lines of force of conductors with special shapes, electromagnetic interaction, Lenz’s law, and Foucault current. These contents are dissected firmly based on science, technology, engineering, and mathematical knowledge. Table 1 presents the content of STEM teaching in the section of magnetic field and electromagnetic induction phenomena that are performed into 4 parts.

**Table 1. The content of STEM teaching in the section of magnetic field and electromagnetic induction phenomena.**

| No. | Contents | Outcomes | Physics | Technology | Engineering | Maths |
|-----|----------|----------|---------|------------|-------------|-------|
| 1.  | The magnetic field lines of conductors with special shapes | Set of experiments of the magnetic field lines of 3 conductors: straight wire, carrying loop of wire, solenoid | The magnetic field of conductors with special shapes | Pressed paper, copper wire, iron fillings | Do experiments to figure out the magnetic field lines caused by special conductors | - Measure to choose appropriate copper wire. |
|     |          |          |         |            |             | - Calculate the number of the wire rings, the diameter of the ring, and the suitable distance between the rings. |
| 2.  | Electromagnetic interaction | - Magnetic interaction experiments between the magnet and the current. - Car driven by magnetic interaction | - Characteristics of the magnetic field - Magnetic interaction | Copper wire, magnet, trash timber, plastic bottle, pressed paper | Manufacture products | - Calculate, measure to make good moving vehicles. |
|     |          |          |         |            |             | - Measure and determine the length of the moving car's track. |
| 3.  | Lenz’s Law | The experimental set used to study the Lenz’s law. | The magnetic line of force of conductors with special shapes | Copper wire, magnet, trash timber, pressed paper | Manufacture products | Measure and calculate to create experimental setup |
The experimental products of the contents of magnetic field and electromagnetic induction phenomena are manufactured from simple, easy-to-find and inexpensive materials. All students can do it themselves under the guidance of teachers. These products are showed in table 2 corresponding to each part of content.

**Table 2.** The experimental products corresponding to each part of content in the section of magnetic field and electromagnetic induction phenomena.

| No. | Contents                                                                 | Experimental products                                                                 |
|-----|--------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| 1.  | The magnetic field lines of conductors with special shapes              | ![A straight wire](image1.png) ![A carrying loop of wire](image2.png) ![A solenoid](image3.png) |
|     |                                                                          | a. *A straight wire*                                                                    |
|     |                                                                          | b. *A carrying loop of wire*                                                            |
|     |                                                                          | c. *A solenoid*                                                                        |
| 2.  | Electromagnetic interaction                                              | ![Vehicle driven by the interaction between electric current and magnet](image4.png)   |
|     |                                                                          | a. *Vehicle driven by the interaction between electric current and magnet*             |
|     |                                                                          | ![Experiment on the interaction between electric current and magnet](image5.png)      |
|     |                                                                          | b. *Experiment on the interaction between electric current and magnet*               |
| 3.  | Lenz’s Law                                                               | ![Lenz’s Law Experiment](image6.png)                                                  |
| 4.  | Foucault current                                                         | ![Foucault current experiment](image7.png)                                           |
Experimental preparation of STEM products is guided by the teacher so the students can do as following suggestions:

1. *Figure out the magnetic field lines of conductors:*
   - A straight wire:
     - Use a piece of straight copper wire (5 mm in diameter) piercing through the paper, sprinkle the iron flings on the paper around the wire and then make the current of 3–4 A flow in the wire, tapping will get the image of the magnetic field lines.
     - The magnetic field lines of a straight wire can be obtained as the image showed in figure 2.

   ![Figure 2. The magnetic field lines of a straight wire in the experiment (on the left) and in illustration (on the right).](image1)

   - The current loop:
     + Using a square paper (20 cm in diameter), cut two small holes in the middle of the paper with the distance between the holes of about 5–6 cm. Use copper wires through round the holes to form a loop (about 30–50 rounds), sprinkle the iron filings around the wire into the paper.
     + The current flow in the wire is controlled at 2 – 3 A. tap lightly on the paper to observe the line of iron filings. The magnetic field lines of a current loop can be obtained as the image showed in figure 3.

   ![Figure 3. The magnetic field lines of a carrying loop of wire in the experiment (on the left) and in illustration (on the right).](image2)

   - The solenoid:
     + A solenoid is a coil of many circular loops wrapped up in the shape of a cylinder. Wrap the copper wire around a can of coke then cut the can to form a solenoid.

   ![Figure 4. The magnetic field lines of a solenoid in the experiment (on the left) and in illustration (on the right).](image3)
+ Use a piece of paper and cut 2 slits on the paper with the distance between 2 slits equal to the diameter of the solenoid. Put the solenoid matched to slits and fix the solenoid with glue then sprinkle the iron filings in the paper around the solenoid.

+ Make the current flow in the solenoid, tap lightly on the paper to observe the line of iron filings. The iron filings on the paper show the magnetic field lines of the solenoid. The magnetic field lines of a solenoid can be obtained as the image showed in figure 4.

2. Electromagnetic interaction: Vehicle driven by the interaction between electric current and magnet

+ The vehicle (a small car) is made from 2 wood spatulas, 2 straws, and 4 plastic caps. The end of the car is attached with a rare earth magnet.

+ Manufacturing gutters (for the car moving on it): An inclined plane made from wood with many trenches. The lower end of inclined plane is designed a coil (the larger the round number, the better). Connect the wires to the power supply and switches to form a closed circuit.

+ Principle of operation: When the vehicle is at the bottom, the force of the magnetic field of the coil acts on the magnet so that the car can move slowly on the top of the inclined plane, then the car moves down. This experiment is very difficult to control the strength of magnetic force so that the car can move up on the inclined plane (figure 5). The main objective of this experiment is calculating and measuring to make good moving vehicles, also determining the length of the moving car's track. The moving of the car on inclined plane by electromagnetic interaction is normally for good students. We will report it detail in another paper.

Figure 5. Illustration of the moving of the car on inclined plane by electromagnetic interaction (on the left) and the experimental product by students (on the right).

3. Lenz’ law experiment

The materials including cans, sponges, candle stick, ink ball pen out of ink, plastic bottles are set up and showed in table 2. Let the magnet move close or away from the wire frame we can determine the movement of the wire frame. Observing the direction of motion of the magnet determines the direction of the induced current. The detail of this experiment will be reported in the teaching process of lesson plan of Lenz's law.

4. Foucault current experiment

Foucault currents are loops of electrical current induced within conductors by a changing magnetic field in the conductor due to Faraday’s law of induction. The experimental setup is carried out by using a can of coke as conductor and permanent magnet.

Let the magnet move around the conductor, the moving of the can can be observed. This implied that there is one induced current in the can. This current is attributed to Foucault current.

3. Pedagogical experiment

We have designed four teaching plans based on products: magnetic interaction experiments, cars driven by magnetic interaction, magnetic line of force caused by conductors with special shapes, experiments on Lenz’s law, experiments on Foucault current to organize teaching under STEM education.
The number of products in the section of magnetic field and electromagnetic induction phenomena taught under STEM education at least as following:

- Magnetic interaction: 2 products
- Magnetic line of force of special wire shapes: 3 products
- Lenz’s Law: 2 products
- Foucault current: 1 product.

In this paper we present in detail the teaching plan for the lesson “Lenz's law of inductive current” in Physics Grade 11 for a period of 45 minutes.

3.1.1. Objectives of lesson plan: “Lenz's Law”

- Knowledge: the content of Lenz’s law
- Skills: Do experiments with Lenz’s law according to STEM documentation; learn how to exploit experiments to draw the relationship between external magnetic field and electromagnetic induction; apply the Lenz’s law to determine the direction of the inductive current.

3.1.2. Materials of lesson plan: “Lenz's Law”

- STEM teaching materials: copper wire, rare earth magnets, plastic bottles, cans, scissors, sponges, paper knives, glue guns, 502 glue, tin and welding torches.
- STEM manual of “Lenz’s Law”
  a. Lenz’s law experiment: This is a set of experiments that help us determine the inductive current directly or indirectly. In this lesson, we introduce a set of experiments that help determine the direction of the induced magnetic field by the direction of the external magnetic field, then applying the right hand rule to determine the direction of the inductive current.
  b. Materials of the experiment
     - Rare earth magnets: help generate magnetic fields with defined direction
     - The coils cut from the cans and attached to the two ends of the light balance scales that can rotate around a fixed axis.
     - The stand of the rotary shaft is attached to the plastic bottle
  c. Theoretical background and the experimental procedure
     - Theoretical background for the experimental design: Interactions between magnets and magnets, electromagnetic induction and magnetic fields caused by a round wire.
     - Experimental procedure:
        - Move the magnet near the wire; we observe the movement of the wire. If the wire moves in the same direction as the magnet, we can infer that direction of the induced magnetic field is opposite to that of the magnet. It is easy to determine the direction of the induced magnetic field.
        - Move the magnet away from the wire, we observe the movement of the wire. If the wire moves in the same direction as the magnet, the magnet is attracting the wire. Then, we can infer that direction of the induced magnetic field must be in the same direction as the magnetic field of the magnet. It is easy to determine the direction of the induced current.
     - Collect data and give conclusion.
  d. Experiment of the Lenz’s Law
     i. Purpose: to study the relationship between the directions of the induced magnetic field and the external magnetic field when the flux sent through the wireframe increases or decreases. Then, make conclusions about the Lenz’s Law.
     ii. Tools and materials
        In order to do Lenz’s Law experiment, we need to use the following materials and tools:
        + Materials: magnets, plastic bottles, cans, candle glue, ink pen balls, paper pins.
        + Tools: Glue gun, scissors, pliers, ruler, and paper knife.
     iii. Processing, assembling experiment
        Step 1: Make round wire from cans
        Step 2: Make scale stand from sponge
Step 3: Make rotary shafts from plastic bottles, paper pins
Step 4: Assemble, complete the test kit
Step 5: Operation, testing
Step 6: Perform the experiment, collect the results and write the report

**iv. Evaluate and discuss the design of experiment**

The evaluating Lenz's law experiments are evaluated via 5 criterias presented in table 3.

| No. | Criteria                                                                 | Maximum scores | Evaluation scores |
|-----|---------------------------------------------------------------------------|----------------|-------------------|
| 1.  | Successfully implement the experiment as scheduled                        | 10             |                   |
| 2.  | Clear observation; the test results have high reliability; determining the given requirements. | 40             |                   |
| 3.  | Demonstrate the principle of structure, principle of operation of the experiment clearly, coherently. | 30             |                   |
| 4.  | Find out answers to questions                                              | 10             |                   |
| 5.  | Active and enthusiastic participation in the experiment.                   | 10             |                   |
|     | **Total**                                                                 | **100**        |                   |

3.1.3. Teaching process of lesson “Lenz's law

a. **Introduction and question**

Teacher (T): When the flux is sent through the variable wire frame, the induced current appears in the frame. So, how to determine the direction of induced current flowing in the wire frame?

Students (Sts): Consider the direction of induced current through experiment.

T: Orient students to do experiments to determine the direction of induced current with simple, easy-to-find materials.

Sts: Explore methods to design the experiment

b. **Processing, manufacturing and conducting experiment: students work in groups**

Groups in the class receive instructions and conduct experiments to study; then, receive materials and tools from teacher to begin processing, manufacturing and conducting experiments. Teacher monitors the activities of groups, provides timely support, and advises them to make sure that groups can complete the task within the required time period.

c. **Report the activity results**

Groups send representatitives to report the results of their activities: Product is the experiment kit and the results of experiment are showed in the table 4.
Table 4. Report on experiment results of student group

| Rounds | Motion of magnet | Motion of round wire | Magnetic flux variation | Relationship between the directions of inductive current and the motion of magnet |
|--------|-----------------|---------------------|------------------------|--------------------------------------------------------------------------------|
| 1      | Magnet approaching the round wire |                      |                        |                                                                                 |
| 2      | Magnet moving away from the wire |                      |                        |                                                                                 |
| 3      | Magnet approaching the round wire |                      |                        |                                                                                 |
| 4      | Magnet moving away from the wire |                      |                        |                                                                                 |

d. Conclusion
- When the magnetic flux increases, the inductive magnetic field is ............ direction with external magnetic field.
- When the magnetic flux decreases, the inductive magnetic field is ............ direction with external magnetic field.
- Infer that the inductive magnetic field always has a tendency ...................... the process of varying the magnetic flux sent through the round wire
e. Conclusion on Lenz’s Law of induced current direction

3.1.4. Conclusion on the lesson content
T gives conclusion to the lesson content.
+ Lenz’s Law: The induced current that appears in round wire produces an induced magnetic field that tends to resist what generates it.
+ Steps of applying Lenz’s law to determine the induced current direction:
  *Step 1*: Determine the direction of the external magnetic field
  *Step 2*: Determine the increasing or falling variation process of the flux sent through wire frame
  *Step 3*: Determine the direction of the magnetic field
- If the magnetic flux falls, the direction of the external magnetic field is the same as that of the induced magnetic field
- If the magnetic flux increases, the direction of the external magnetic field is opposite to that of the induced magnetic field
*Step 4*: Apply the right hand rule to determine the direction of the induced current
+ Application: T gives some cases for students to determine the direction of the induced current.

3.1.5. Results
Through the implementation process in class 11A2 at Thai Nguyen High School with 28 students divided into 4 groups, we have obtained the following results:
+ The process of manufacturing, experimenting: Students were very excited, actively involved in the process of doing experiments on the basis of guidance from STEM documents. However, there were many students confused in the use of tools: fine art saw, glue gun, drill, etc. Some groups did not know how to make rotary shafts, quite embarrassed to roll copper wire tube, frame. However, when instructed by teacher, they acquired the basic skills of using the tools in the manufacturing process and completing the tasks assigned.
+ Reporting Results: Groups reported the results of their work. Generally they had good reporting skills, full presentation of the structure, effect of the components, the principle of product operation, advantages - limitations of the product.

Through the teaching process under STEM orientation, students are facilitated to develop competencies that are expressed through the table 5.

| Competencies                        | Manifestation                                                                 |
|-------------------------------------|-----------------------------------------------------------------------------|
| Studying STEM documents             | Students actively seek information about the tools, materials, principles of manufacturing, principles of operation of the product in STEM documents. |
| Stating and solving problems        | The groups have proposed and set out solutions for the given tasks. Some groups recommend excellent solutions. |
| Reviewer                            | The students are quite enthusiastic in group discussions, giving a lot of arguments and discussion about the manufacturing process, as well as the principles of operation. |
| Practice                            | Groups know how to manufacture products, how to divide specific tasks and successfully complete the products as required. |
| Communication                       | Students in groups have had discussions and exchange of ideas to complete the tasks. |
| Calculating                         | Know how to calculate the collected data, utilize materials in optimal way, and arrange time to make products. |
| Group work                          | Know how to divide specific tasks, solve problems together. |
| Creativeness                        | Recommend solutions to the task; some groups also offer a variety of solutions to choose the optimal one. |
| Presentation                        | Students have good way to present their group products and results. |

4. Conclusion
This work demonstrates that the STEM-oriented teaching process is highly feasible. This process not only meets the 45-minute requirement but also creates excitement for students, enabling them to develop the necessary skills and abilities: presentation, teamwork, critical thinking, problem solving, creativity, etc. Especially, this process ensures that students are equipped with the basic knowledge of the subject and the knowledge of other disciplines such as technology, science, mathematics. It can be seen that STEM-oriented teaching process should be studied and experimented to gradually apply in the process of high school teaching to meet the change of the secondary education reform.

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