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Integrating Effective Pedagogies in Science Education with a Design of Alternative Experiments on Electromagnetics

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Learning electromagnetics often involves dealing with problems with strong mathematical skills or thinking about problems in abstract and multiple spaces. Moreover, many students are often unable to explain some related physical phenomena using the appropriate electromagnetic principles. In this paper, we report on integrating two effective pedagogies in science education. Those were STS (science, technology and society) instruction and guided discovery approach by designing some alternative experiments on electromagnetics at university undergraduate level. Based on a Radio Frequency Identification (RFID) system, three sets of scientific investigation activities are specifically designed for helping undergraduate physics and engineering students explore the electromagnetic phenomena in real-world situations and acquire a better understanding of the inter-relationship amongst science, technology and society.

Keywords: experimental design, guided discovery, Radio Frequency Identification, STS instruction

INTRODUCTION

Electromagnetics is demanded as one of the most important modules in the fundamental physics for undergraduate students at different college levels. Understanding the electromagnetic principles is a requirement for freshmen and sophomore students majoring in science and engineering. Although electromagnetics finds wide applications in modern life, students have difficulties in applying electromagnetic principles while maintaining a related physical comprehension. The underlying reason is that dealing with electromagnetics problems demands of strong mathematical skills and requires students to think about problems in abstract and multiple spaces (Mukhopadhyay, 2006).

To reduce barriers of complex mathematics in learning electromagnetics, computer-based simulations have already been developed one after another to show different kinds of practical applications of electromagnetics (Beker, Bailey and Cokkinides, 1998). In addition, many graphical visualization packages are to illustrate how the theory could be utilized to get the practical problems solved (Lowther and Freeman, 1993; Excell, 1993; Coren, 1993; Hall and Cendes, 1993). Indeed, the teaching of electromagnetic theory has

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State of the literature

- Although electromagnetics finds wide applications in modern life, students usually encounter difficulties when applying electromagnetic principles in solving related problems or interpreting physical phenomena.
- Researchers make effort to improve students understanding on eletromagnetics with various computer-based teaching techniques, however, confusions still exist in students' minds whether software reflects the physical phenomena.
- STS approach for science teaching has been limited to special educational spectrum. It was apparently rare to find that college science teaching based on an STS approach, particularly for eletromagnetics module.

Contribution of this paper to the literature

- Central to this study is the search for effectiveness of instructional strategies to help students acquire a better understanding on the application of electromagnetics.
- Integrating pedagogies of STS instruction and guided discovery approach with the design of alternative experiments on electromagnetics facilitates students to investigate electromagnetic phenomenon in real-world situation.
- Through the guided discovery approach in the STS learning process, students are placed in the inquiry environment and are considered to be central. It is good for them to generate their own idea for the investigation, without relying purely on the standard answers.

benefited tremendously from the developments of animation, simulation and visualization software, which are displaying the electromagnetic fields and electromagnetic waves (Grosse and Tirado, 1996; Hoburg, Mullan and Fugate, 2000). However, confusions still exist in students' mind whether the animations, simulations or visualizations shown in the software are real-world examples and whether they reflect the physical phenomena.

Science, technology and society (STS) instruction, which has been a major reform in Science Education for over 30 years, does indeed involve with real world contexts, problems and issues that provide for applications and connections in students' life (Bybee, 1985; Hurd, 1986; Roy, 1985; Yager, 1996). NSTA has defined STS as the teaching and learning of science and technology in the context of human experience (NSTA, 2006). It emphasizes the importance of "technology" to science, as "science" is to contain almost pure science, in particular that the basic concepts of the disciplines are routinely utilized to define a course. As well, "Society", which may be more of an emphasis in STS teaching, conveys the image of socially constructed knowledge (Yager, 1992). Students are usually engaged in the STS science class focusing on the social dimensions, including the use of local resources, identification of problems with local impact, solving real-life problems and so on (NSTA, 2006).

However, STS approach for science teaching has been limited to special educational spectrum, especially from K-12 (Yager and Akcay, 2008). Although in Bybee's research (Bybee, 1987) the responses from college instructors agreed that 25% of the science class time should be devoted to the related technology and social issues, it was apparently rare to find that college science teaching involved STS approach around the world (Huang, 1992). According to the result of a survey (Streitberger, 1988), freshman and sophomore college students responded that little attention was paid to related science to personal, society, and political situations by instructors. Thus, we claim that more STS efforts should be made for college science instruction which is to increase student learning interest and encourage students to find the need and value of what they learn about the science.

In this work, we develop three sets of alternative investigation activities for students to explore electromagnetic phenomena in real-world and to form a strong sense of the science, technology and society (STS) connection. STS connection are grounded in socio-technological understanding, that is, systematic knowledge of the mutual relationship among technical objects, the natural environment and social practice (Ankiewicz, Swardt and Vries, 2006). In order to stimulate students to realize the application of the related electromagnetic principles and develop their scientific investigation mindset, a guided discovery approach will be embedded in students' investigation process. A concise outline of those two kinds of effective pedagogies will be given in the Subsections 2.1 and 2.2 below.

BACKGROUND AND APPROACH

STS background

In telecommunication, frequency is a very important quantity used to describe the property of electromagnetic wave, whose spectrum extends from low frequencies end to ultra-high frequencies end. In different regions of the whole electromagnetic spectrum, electromagnetic radiation is generated and detected by different physical mechanisms or devices. This is often beyond students' comprehension, since most types of electromagnetic radiation are invisible.

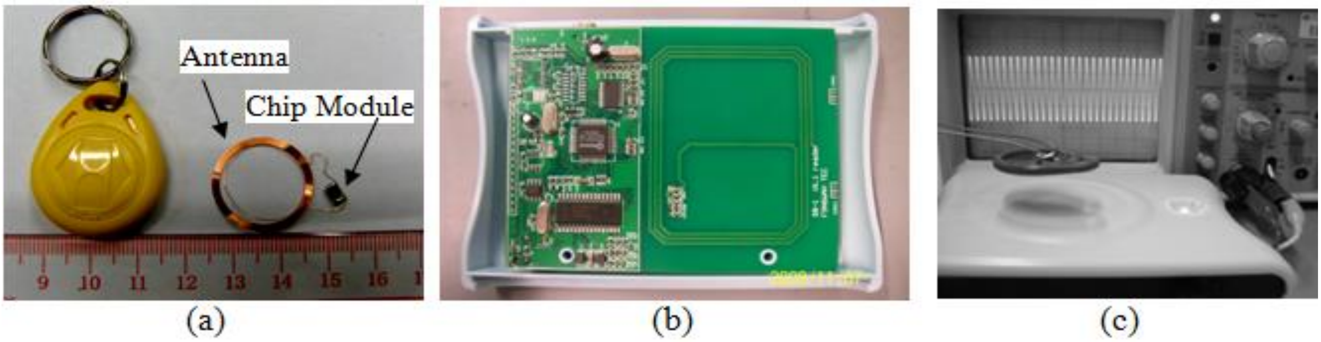

Figure 1. Experimental materials: (a) an encapsulated RFID card and a card inlay as placed on a ruler. (b) circuit board for an RFID card reader with antenna inside. (c) oscilloscope of the signal from the RFID card induced by the card reader

In an effort to make students gain an understanding of how electromagnetic radiation interacts with matter and how science, technology and society (STS) interrelate with each other, some investigation activities are specifically developed on the Radio Frequency Identification (RFID) system (Hagl and Aslanidis, 2009) using some specific Integrated Circuit (IC) cards and card reader (Figure 1). Data are allowed to be read and stored without requiring either a line of sight between the RFID card and the reader or the two contact with each other (Chen and Thomas, 2001). The RFID system chosen in the present study operates at high frequency of 13.56MHz. Its energy is transferred using the magnetic component of electromagnetic field. The reader, through its antenna, powers up the RFID card by emitting a time-varying electromagnetic field, which is called Radio Frequency (RF) field. The RFID card, in which there is a small antenna bounded as a closed loop, feels the effect of the RF field and a voltage is induced across the antenna. When energizing, the RFID card resonates the same signal and sends it back to the reader at the identical frequency of 13.56MHz. Then the communication is built between the RFID card and reader.

The voltage which is generated across the RFID card antenna through the RF field produced from the reader is defined as:

$$V = 2\pi fNSQB_0 \sin\alpha$$

Where:

f : *the frequency of the signal (13.56MHz)*

N : *the number of turns in RFID card antenna loop*

S : *the area of the RFID antenna loop in square meters*

Q : *the quality factor*

B_0 : *the strength of the arrival magnetic field*

α : *the angle between the RFID card surface and the RF field*

For scientific investigation, students are not required to have a good prior knowledge on the internal structure or circuit of the RFID card and its corresponding reader, which are both completely sealed. Instead, they should put forward some appropriate hypothesis to explain the mechanism of the RFID system. In the learning process, the knowledge on the related principle of electromagnetic field and electromagnetic wave will be constructed by the students themselves. STS connection is built through the investigation process of studying the mechanism of the RFID system.

Guided discovery approach

The discovery approach is based on the theory of constructivist learning (Savery and Duffy, 1996; Yager, 1991), which requires a student-oriented learning environment. Unlike the traditional teacher-centered instruction where a teacher directly controls the whole teaching and learning process, students are encouraged to show their constructivist perspective for the progress of learning and knowing. During students' learning progress, the instructor provides needed help to promote them acquiring knowledge and developing a rich understanding of concepts, principles and theories (NRC, 1996). Since most students may lack a good mastery of the scientific investigation skills and the scientific knowledge underlying this system may be quite difficult, the conventional discovery approach may be too challenging to the students. Hence, a guided discovery approach is introduced to take the lead in students' inquiry process, where the teacher acts as a guide.

Figure 2 illustrates the entire procedure of students' guided discovery activities. At the beginning for each experimental investigation, there is a main research question posed to stimulate students to think about the technique behavior and its related science knowledge. Then students are encouraged and required to brainstorm as many ideas as possible about how to carry out the exploration. Before the activities are executed, more detailed questions are put to provide students some clues about a more appropriate investigated process. When students finish the discovery activities with the experimental results obtained, they are asked to

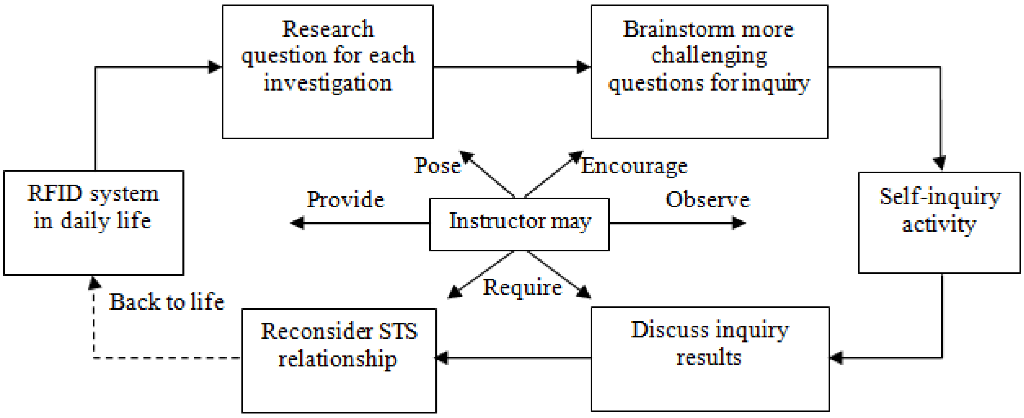

Figure 2. Guided discovery activities and the instructor's roles

deeply ponder over how to explain the physical phenomenon with the electromagnetic principle and how the science knowledge is reflected in real-life RFID card and the reader of RFID system. The last step is an essential component, because in this step, students could reconsider the relationship between science, technology and society, gaining an insight into the application of science to technology and society.

In the guided discovery approach, the instructor plays many important roles in all aspects of the activities. This approach does not only seek to advance student learning by providing them with experimental discovery experience, but also allow them to connect and extend their science content knowledge being studied to real-life or authentic situations.

THE SCIENTIFIC INVESTIGATION ACTIVITIES

When guided discovery approach is integrated with STS in the study of the RFID system, students are required to address the following three questions: (1) What is the frequency of inductive RFID system? (2) What is the effect of environment on RFID system? (3) What is the effect of the orientation factor on RFID system? In this section, the guided discovery process involves a serial of scaffolding teaching (Hmelo-Silver, Duncan, & Chinn, 2007) activities for students to study each research question. The scaffolding includes the following hints: the main research issue, detailed questions, some additional needed cues in the investigation, the explanation of the experimental result for discussion, and the STS relation.

Determine the frequency of inductive RFID system

As one property of electromagnetic wave, the operating frequency of communication between the RFID card and reader corresponds to the frequency of radio wave. Operating frequency is also an importance parameter of various devices in daily life. However, students seldom consider it. Therefore, it is a necessity for a student to study the feature the working frequency of RFID system. Thus, determining the frequency of inductive RFID system is to be one of the research issues.

Detailed questions are raised as follows to assist students to carry out the investigation.

(1) How could you obtain the operating frequency of a RFID card or reader?

(2) What is the magnitude of the operating frequency?

(3) What property does the electromagnetic wave of that frequency have? Is it a long wave or a short wave?

It is quite important to get students to understand that there is a connection between technology (i.e. the RFID system) and scientific knowledge. The communication mechanism between the RFID card and reader has been permeated with scientific knowledge which students have learned in the class. After determining the frequency of inductive RFID system, students should judge whether it is a high frequency (HF), a low frequency (LF) or other type of frequency in accordance to the range of different regions in the electromagnetic spectrum. Furthermore, the question that the electromagnetic wave of the RFID system is a long wave or a short one guides students to consider the relationship between wavelength and frequency, leading students to make a connection between scientific knowledge and the technology used in our daily-life. Meanwhile, it helps students develop an insight on science in the society and get an understanding of STS relationship through the investigation activities.

Factors affecting the performance of RFID system

According to Faraday's law of induction, the induced voltage is proportional to the amplitude of the magnetic flux through the antenna loop. However, for the actual use of the RFID system, some obstructions inevitably exist in the RF field between the RFID card antenna loop and the reader antenna loop (Dobkin and Weigand, 2005). One situation is that the RFID card and reader are usually packaged a plastic shell. Hence, the next issue for investigation could be about why they use plastic as the shell, but not metals or other materials. Students are asked to think about this situation and do some experiments to study the effect of environment on the RFID system; in particular, to verify that plastic is a better choice than metals as the shell of both the RFID card and reader.

With the research questions, students start to discuss how to carry out the experiments to collect the relevant scientific evidence. After the discussion, students could be posed with the following questions for subsequent scientific investigation activities to challenge their prior or pre-existed knowledge:

(1) Why do not use metals as the shell of the RFID card and reader? Do metals greatly influence the electromagnetic induction in the operation of the RFID system?

(2) What other materials would you like to choose for testing?

(3) How could you ensure a fair test for experiments with different materials under a nearly controlled condition?

We pose an experimental design as an example for investigating the effect of environment on the RFID system. This example could be used for teachers to expand more cases, as well as for students to compare them with their own exploration.

Since plastic is usually used as the shell of the RFID card and reader, plastic should be chosen as one of the testing materials. As for metal, iron and aluminum are selected. There is a need to add a controlled experiment in which there is no obstruction inserted between the RFID card and reader. For a fair test, students need to make sure that all experiments with different materials are carried out under a nearly identical condition, i.e. the distance between the RFID card and reader should be fixed. Hence, the RFID card should be fixed in a stable position near the reader. Furthermore, all the selected testing materials should have the same size.

An oscilloscope which is capable of measuring signals up to 20 MHz is used to show the peak-to-peak values of the voltages (Vpp) generated across the IC antenna with different testing materials inserting between the RFID card and reader. A set of sample data is shown in Table 1. The peak-to-peak value of voltage (Vpp) generated across the IC antenna is 1500 mV, without putting any materials in the RF field. The oscilloscope displays each peak-to-peak voltage value in different situations as well.

Table 1. The peak-to-peak values of voltages (Vpp) in situations with different testing materials inserted between the RFID card and reader.

The testing materials	none	iron	aluminum sheet	plastic plate
The peak-to-peak values of voltages (Vpp)	1500 mV	160 mV	240 mV	1500 mV

From the results, students will get an idea that the environment has an effect on the RFID system and diverse materials influence the experiment differently. In particular, metal check and metal sheet weaken the induced voltage considerably. However, when a plastic plate is inserted between the RFID card and reader, there is almost no decrease in the value of the peak-to-peak voltage. Discussions about this phenomenon would be taking place within each individual group. Furthermore, the question could be posed to students to stimulate in-depth discussion: could you explain why metal diminishes the induced voltage so significantly? To answer this question, relevant principles of electromagnetics should be further introduced and students may also be expected to acquire the knowledge by themselves through self-regulated reading.

On one hand, when the metal is inserted between the RFID antenna and the antenna of the reader, the energy of the RF decreases as it is absorbed by the metal. In the meanwhile, the metal generates another magnetic field, changing the distribution of RF on the metal surface, and the magnetic lines become flat. Therefore, the RFID antenna could not get enough electromagnetic energy through cutting the magnetic lines. On the other, the motion of the free charges inside the metal is influenced by the electromagnetic field, and the skin effect occurs. The skin effect also has an impact on the induction of the RFID system. The depth that the electromagnetic wave could reach inside the metal is defined as skin depth, given by:

$$\delta = \sqrt{\frac{\rho}{\pi f \mu_0 \mu_r}}$$

Where,

ρ : *the resistivity of the metal*

f : *the frequency of the signal (13.56M)*

μ_0 : *the vacuum permeability*

μ_r : *the relative permeability of the metal*

Usually, the resistivity of the metal ρ is much smaller than that of other materials (e.g., plastic). And the value of skin depth δ is so small that electromagnetic wave could hardly penetrate through the metal and continue to propagate to RFID antenna. The Faraday's law of induction illustrates that the induced voltage across the antenna is proportional to the strength of the external magnetic field. While, the strength of applied magnetic field has become small due to the skin effect, the voltage has been significantly reduced too.

Thinking and discussing the question about why metal diminishes the induced voltage so significantly, instigates students into contemplating the practical product and technology in terms of the principle of electromagnetic wave propagation they have learned, connecting the STS relation.

Effect of the orientation factor on RFID system

Apart from the effect of material medium, the position of the RFID card as relative to the surface of the reader could also be another factor. In a simple term, it refers to the angle between the RF field and the RFID card surface. Therefore, it will be interesting to put forward another topic to investigate the effect of the angle between the RF field and the RFID card surface on the RFID system.

To help students study this research topic through a guided discovery process, they are asked to brainstorm as much related questions as they can to support the investigation. We may list out the following questions for students to consider after their own discussions:

(1) How could you obtain different angles between the RF field and the RFID card surface?

(2) How to control all the other factors to make sure that the angle is the only variable?

(3) What particular relation is presented between the angle and the induced voltage?

The above guided questions facilitate student discovery activity. Below we come up with two cases as examples on how to explore the issue.

Case 1: fix the position of the RFID card but vary its inclination.

In this case, the RFID card is initially placed at the center of the reader surface and in parallel with the surface so that the angle between the RFID card surface and the RF field is 90 degrees. From the initial state, fix the position of the RFID card while changing the angle. The angle is measured with the help of a protractor and a ruler. For every 10 degrees of the angle, a peak-to-peak value of the induced voltage is recorded from an oscilloscope. When the angle is just 90 degrees, the oscilloscope shows that the peak-to-peak value of voltage is 6.0 V. Table 2 illustrates the data of ten peak-to-peak values of induced voltages for different angles.

Figure 3 shows the graph for the data in Table 2. This graph has a good educational use because students will be asked to fit a best curve with those ten data points in Figure 3. It could be a hint to get students to think about the principle of the electromagnetic induction and the relation between the induced voltage and the angle between the RFID card surface and the RF field. In accordance with the Faraday's law of induction with the following equation:

$$V = 2\pi fNSQB_0 \sin\alpha$$

the induced voltage is proportional to the sine of the angle between the RFID card surface and the RF field. Therefore, the data in Figure 3 should be fitted to be a

Table 2. Peak-to-peak values of induced voltages for various angle of the RFID. The angle is measured between the RFID card surface and the RF field

angle (degree)	0	10	20	30	40	50	60	70	80	90
Vpp(V)	0.4	0.8	1.0	1.5	2.0	2.3	3.3	4.0	5.0	6.0

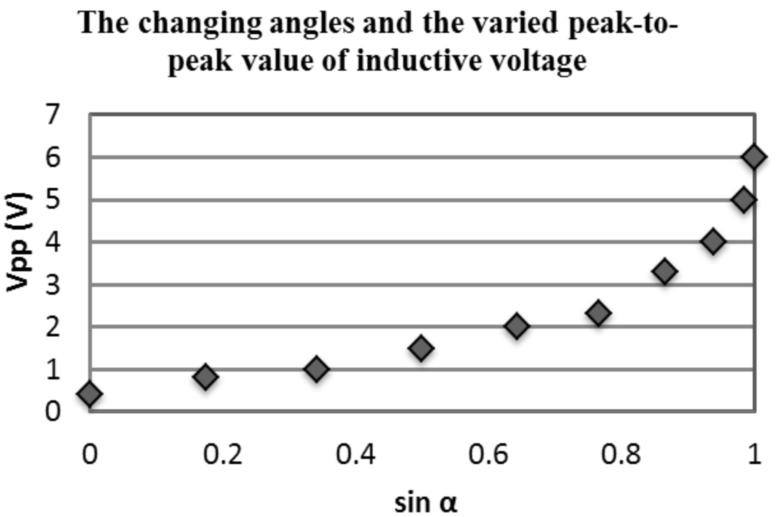

Figure 3. The variation of the peak-to-peak values of induced voltages against different sine angle which is between the RFID card surface and the RF field

linear line. Students are encouraged to discuss why most of the data are not exactly on or even not near the line. To go a step further, they need to consider a better scientific method for the measurement.

Case 2: fix inclination of the RFID card but vary its position.

In this case, the inclination of the RFID card is fixed in such a way that it is always lying in parallel with the reader surface, but its position is changed to ensure that the angle of RFID card surface and the RF field is changing. In this investigation, a key step is to find out how to measure the distance between the RFID card and the central point of the RF field. There is a delicate design of putting a graph paper on the center of the reader surface, with a matrix of small 1 cm x 1 cm squares drawn on the paper. The outline of the reader is traced on the graph paper (see Fig.4).

Then the RFID card could be moved freely in any different directions from the center of the graph paper, such as East, South, West, North, Southeast, Northeast, Southwest and Northwest. At different points, there are various peak-to-peak induced voltages across the RFID antenna through the RF field produced from the antenna inside the reader. A set of voltages have been read and recorded corresponding to its position on the graph paper in Fig. 4 from which we could get a rough picture of the contour map for the induced voltages. The strongest electromagnetic induction appears when the RFID card is placed on the center of the reader surface with a highest voltage. Then, the voltages start to decrease from the middle to the end in every direction.

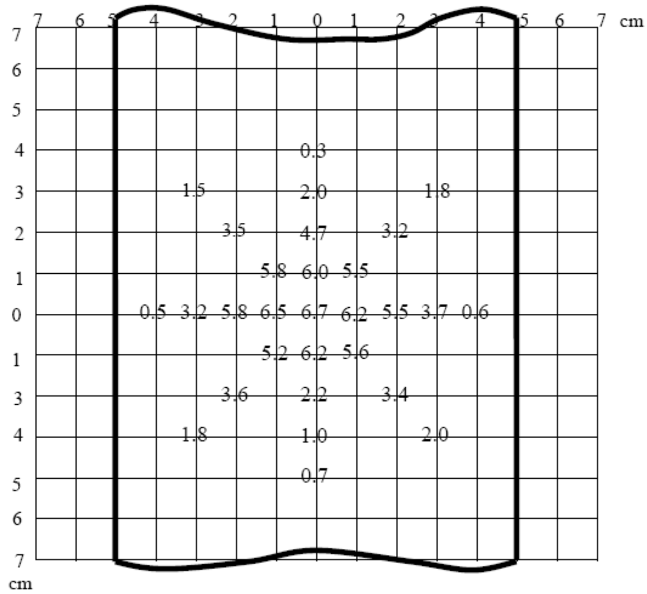

Figure 4. A delicate design of putting a graph paper on the center of the reader surface. On the paper, a matrix of small 1 cm x 1 cm squares is drawn. The outline of the reader is traced on the graph paper

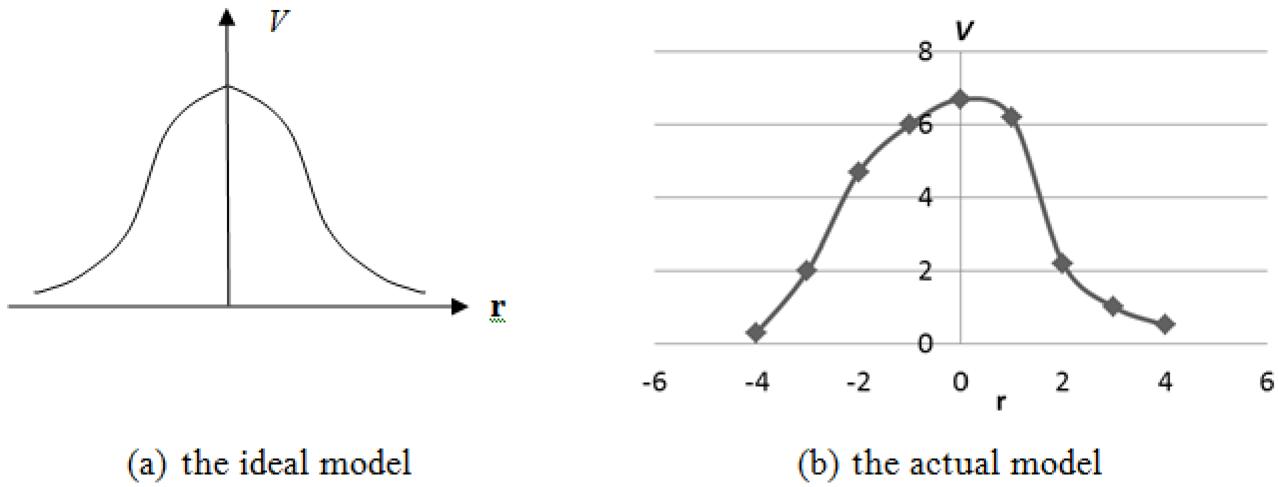

Figure 5. The relation between the induced voltage V and the full displacement vector r. r is the full displacement vector from the antenna in the reader (approximate to the central point on the graph paper) to the point at which the RFID card is placed

Based on the result of the investigation, students are encouraged to strengthen their subject knowledge in order to explain the appearance of the voltage distribution. According to the Biot–Savart law, the magnetic field at any point in space generated by an electric current (along closed curve) is described as:

$$B_p = \frac{\mu_0}{4\pi}\int_C \frac{Idl \times \mathrm{r}}{|\mathrm{r}|^3}$$

In this study, *I* is the electric current though the antenna inside the reader. r is the full displacement vector from the antenna in the reader (approximate to the central point on the graph paper) to the point at which the RFID card is placed. Since the RFID card is parallel to the surface, the equation of the inductive voltage across the RFID antenna at different points is transformed to:

$$V = 2\pi fNSQB_p = \frac{\mu_0 fNSQ}{2}\int_C \frac{Idl \times \mathrm{r}}{|\mathrm{r}|^3}$$

Figure 5 (a) shows the ideal model about the relation between the voltage V and the full displacement vector r, in terms of their relation in the transformed equation above. From the experimental result in the graph paper (Fig. 4), take the data in the direction from the north to the south as an example and draw a figure to show the relation of actual pattern of V- r, which could be found in Figure 5 (b). Similar diagrams could be drawn from data in other directions in Figure 4. In contrast to two diagrams in Figure 5, the actual model of V- r is very close to the ideal one. After collecting data and drawing diagrams, it is an important step to guide students to explore some relative theory or principles (i.e. Biot–Savart law in this section) to explain what they have discovered from the experimental result.

CONCLUSION AND DISCUSSION

In this paper, we develop a STS learning module to help students acquire an effective understanding of electromagnetics through a guided discovery approach. In the STS learning module, experiments are developed with RFID system using the specific RFID cards and card reader, in an effort to make students gain an understanding of how electromagnetic radiation interacts with matter. It is an exemplar on STS approach in the sense that its content consists of an interaction between science and technology, involving a technological artifact which is the RFID system and its application in our daily-life. The guided discovery approach is to facilitate students' effective scientific investigation. Scaffolding is provided by the instructor with stimulating questions for students to study each research issue in order to support their discovery learning and understanding. Cases are provided for the instructor to elaborate examples to students, as well as for students to compare them with their own investigation. In brief, we integrate effective pedagogies of STS instruction and guided discovery approach with the design of alternative experiments on using the RFID to investigate electromagnetic phenomenon in real-world situation.

STS instruction in science education provides an effective way for students to connect scientific principles with technology. It helps students focus on real-world issues which involve science and technology components in science classes, rather than getting the basic concepts or principles directly for the discipline. Students are allowed to learn and apply the concepts and disciplines in real life contexts and situations. Opportunities are provided in STS education for students to extend scientific knowledge beyond the classroom to their local society. Its purpose is to increase student interest in learning science by placing scientific and technological knowledge in daily-life situation.

In the STS learning process, students' activities should be learner centered and the conventional cook-book approach on laboratory practice would be given up. Students are considered to be central in the STS approach where students generate their own idea for the investigation, instead of relying purely on those provided from the instructors or learning materials. Students brainstorm questions, take research action in the inquiry, participate in the discussion and further develop the related science knowledge through social interactions and self-learning. STS means that students are involved in questions, issues and experiences which are related to their lives. By responding to these questions and being engaged in the experiences, students will be empowered to be active, responsible and to develop the scientific literacy by themselves (Yager, 1992).

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