Augmented Reality Teaching Aid for Electromagnetic Induction for Middle School Students

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Abstract  Understanding electromagnetic induction, whose study is part of the middle school curriculum in Japan, is difficult for students. Thus, this study developed an augmented reality (AR) teaching aid for electromagnetic induction for middle school students. Magnetic lines are illustrated in three dimensions as an AR using conventional tablet PCs. Lessons were conducted with 127 middle school students, and the changes in their explanation of the principle of electromagnetic induction were investigated before and after using the teaching aid. The investigation revealed that only 3% of the students could explain scientifically the principle of electromagnetic induction before using the teaching aid; however, 63% of them were able to provide a scientific explanation after the AR teaching aid was applied.

Keywords: teaching, middle school student, AR, electromagnetic induction, tablet PC

1. Introduction

In Japan, although the basic principle of electromagnetic induction is taught in the eighth grade of middle school, its understanding is difficult even for some university students (1). This is because magnetic fields cannot be directly observed with the eye. Thus, for students to understand electromagnetic induction visually, the concept of magnetic line is introduced (2). In middle school, magnetic lines are depicted in two dimensions through the illustration of patterns created by iron filings placed in a magnetic field or measurements using a compass for teaching purposes. However, counting the numerical change of the magnetic lines on the coil requires knowledge of the three-dimensional spatial concept of magnetic lines.

In recent years, teaching aids using augmented reality (AR) have been developed to enable the visualization of three-dimensional magnetic fields. Matsumoto et al. used a head-mounted display connected to a PC in the development of a teaching aid for visualizing magnetic lines in three dimensions as an AR (3). In addition, Cai et al. developed a teaching aid using a motion-sensing device called Kinect (4). As these teaching aids are expensive, they are not suitable for use in actual teaching in schools. However, tablet PCs are beginning to spread throughout the compulsory education system in Japan, and there are expectations that the development of AR teaching aids using inexpensive tablet PCs will make AR-based teaching aids more accessible. To date, an AR-based teaching aid for electromagnetic induction that can be used in middle school has not yet been developed, nor have the learning effects due to the application of an AR-based teaching aid been verified. Therefore, the use of an AR teaching aid is expected to enable students to explain electromagnetic induction scientifically.

2. Motivation

The motivation of this study was to develop a teaching aid that displays the magnetic lines surrounding an actual magnet using a tablet PC by considering the magnet as an AR marker, and that explains that the numerical changes in the magnetic lines passing through a coil correspond to electromagnetic induction. Furthermore, classroom practice using the teaching aid in ordinary classes for eighth-grade middle school students were conducted to verify the effect of the proposed teaching aid.

3. Development of the Teaching Aid

We developed a teaching aid that recognizes a magnet using 3D AR markers (an AR magnet) and displays magnetic lines to teach students about induced
current generation by moving the AR magnet relative to a virtual coil.

3.1 Magnet with an AR marker

An overview of the 3D AR magnet and the structure within the AR magnet (inset image) are shown in Figure 1. A random pattern is printed on the marker, which is authenticated using the pattern with the color converted to grayscale. As shown in the inset image, the body of the AR magnet is made of polystyrene foam, and disc-shaped neodymium magnets (2 mm thick and 12 mm in diameter) are attached to each end of the body. The AR magnet is considered a bar magnet. However, since the use of two neodymium magnets will result in the induced current having a different direction compared to that of an actual bar magnet, the magnets are linked with a ferromagnetic iron bolt 10 mm in diameter.

Figure 2 shows the measurement of the induced current when the AR magnet is moved relative to the coil with a galvanometer. The coil was made by wrapping a 0.29 mm diameter copper wire 400 turns around a PVC pipe with an external diameter of 60 mm. The inductance of the coil was 17 mH.

3.2 Software details

The AR software was developed on Unity 2017 using C# language and the AR library “Vuforia.” The software runs on the Android operating system and was designed to perform the following two operations: depict the magnetic lines surrounding an AR magnet using AR (as shown in Figure 3a) and confirm that the current induced when the AR magnet is moved relative to a virtually displayed coil (a virtual coil) is induced (as shown in Figure 3b).
shown in Figure 3b). Since the software operates on tablet PCs with low processing power, the calculation processing was approximated and simplified as shown below.

The magnetic field originated from a coil, in which a constant current flows and which is located at the center of the AR magnet, is considered the origin of the magnet field. To simplify calculations, the coil is considered as single-loop. As the spatial distribution of the magnetic field calculated from the single loop differs from that of the actual magnet, the magnetic lines shown in the AR environment are not real-time calculation results but rather a depiction of 15 magnetic lines using the results obtained from previous calculations (Figure 3a).

When the “Display Coil” button, shown at the bottom left of Figure 3a is pressed, a virtual coil appears, as shown in Figure 3b. The virtual coil is merely an image generated by the software, and the magnetic field induced when the current flows through the virtual coil is not calculated. The magnetic field from the single loop in the center of the virtual coil is calculated and the time derivative of the magnetic flux is considered as the induced current. When the current is induced, a light bulb installed on the virtual coil lights up to red and the bulb glows in response to the induced current.

Since the purpose of the teaching aid is to show that the numerical changes in the magnetic lines within the coil correspond to the induced current, the direction of the generated current is not displayed.

A software with the above specifications was developed and confirmed to operate seamlessly on a Nexus 7 (2013) with a Qualcomm® Snapdragon™ S4 Pro 8064 quad-core CPU operating at 1.5 GHz with a RAM memory of 2 GB.

4. Classroom Practice

A 50-minute classroom practice was conducted with four classes of eighth-grade middle school students (127 students) from October 19 to 22, 2018. The AR experiment was conducted using one tablet per three or four students. The teacher gave only basic instructions such as launching the software, and the students freely moved the AR magnet.

As the prerequisite knowledge, electromagnetic induction had already been learned by students and the following two general experiments were conducted.

Exp1: Observation of the compasses placed around the magnet (Figure 4).
Exp2: Measurement of induced current generated by the relative motion of coil and magnet using a galvanometer (Figure 2).

Students learned from Exp1 that the magnetic field is represented by magnetic lines. In addition, they learned from Exp2 that the induced current is generated by the mutual movement of the coil and the magnet. By combining the two results, students are expected to understand that the principle of electromagnetic induction lies in the change in the number of magnetic lines in the coil. However, for many students, combining the two results is not easy. Thus, the AR experiment is expected to make it easier for students to combine the two results.

After performing conventional the two experiments shown above, a “pre-test” was conducted through a questionnaire. The same questionnaire was conducted again after the AR experiment for the “post-test.” The educational effects of the teaching aid were assessed by comparing the results of the pre- and post-test questionnaires. Students had already learned the concept of magnetic lines from observations of patterns on iron filings around magnets.

5. Questionnaire Investigation

The level of understanding of electromagnetic induction was investigated using the answers to the following question: Using terms such as “magnetic lines,” explain scientifically how current is generated in a coil.
during electromagnetic induction.

The results of the students’ responses in the pre- and post-tests were classified into 11 types, as shown in Figure 5.

Classes A to H presented responses containing the term “magnetic lines.” Class I responses did not contain the term “magnetic lines” and only explained the results of the experiment, i.e., that the induced current was generated when the magnet moved. Class J presented blank answers. Class K responses did not contain the term “magnetic lines” and the content they described could not be understood.

Details of classifications of classes A through H are described below. Classes A through C denote responses stating that the changes in the magnetic lines passing through the cross-section of the coil correspond to the induced current. Responses that explicitly mentioned numerical changes were classified into “Class A,” responses that mentioned that “the amount of magnetic lines changes” were classified into “Class B,” and responses that did not explicitly state what aspect of the magnetic lines changed but mentioned that “the magnetic lines change” were classified into “Class C.” Classes D through H present responses containing the term “magnetic lines,” but are not classified into classes A through C.

In the pre-test, the most common response was a blank sheet (J), accounting for 70% of the answers, followed by responses with answers merely explaining the phenomenon (I), corresponding to 9% of the students.

In the post-test, the most common responses were explanations of the numerical changes in the magnetic lines (A), accounting for 44% of the responses, followed by explanations of the changes in the number of magnetic lines (B), corresponding to 19% of the responses, and explanations of the changes in magnetic lines (C), corresponding to 15% of the answers.

6. Discussion of the Results

The description that explains more accurately that the derivative of the magnetic flux with respect to time is the induced current is that of class A. Class A responses, which were not found in the pre-test, increased to 40% in the post-test. Moreover, 46% of the students whose responses were classified as “Class I” and 64% of the students whose responses were explained only the results in the pre-test yielded “Class A” responses in the post-test.

Next, we consider the classes B through H, in which students attempted to give a scientific explanation using the term “magnetic lines.” A Class B response suggests an understanding of the principles of electromagnetic induction despite an inaccurate explanation since, although the meaning of the expression “the amount of magnetic lines” is unclear, it can be inferred that this response refers to the number of magnetic lines, or the density of magnetic lines, within the coil. Class C

![Figure 5. Classification of the Pre- and Post-test Results.](image-url)
responses were found only in the post-test results and suggest that students may have comprehended the phenomenon as a change in the direction of the magnetic lines or something other than the number or density of the magnetic lines within the coil, suggesting a lack of understanding. Class D responses were found only in the pre-test results and can be deemed incorrect because students comprehended that the magnetic lines changed direction because the magnet moved within the coil; however, students did not comprehend it as the accompanying numerical change in the magnetic lines. Classes E and H responses can also be deemed incorrect as they indicate that students think that the induced current will be generated if a steady magnetic field is present within the coil. Class F responses are also incorrect because they reveal that students believe that only the magnetic field above the coil (and not the one within the coil) contributes to induced current generation. Lastly, Class G responses are incorrect because they do not explain the numerical changes in the magnetic lines when the magnet is moved.

In conclusion, Classes A and B responses are considered to denote a correct understanding of the principle of electromagnetic induction, thus providing a scientific explanation for this phenomenon. Therefore, while only 3% of the students were able to explain the principle of electromagnetic induction with a conventional experiment, 63% of the students were able to correctly explain electromagnetic induction after learning through the AR teaching aid. These trends attest the effectiveness of the proposed AR-based teaching aid.

7. Summary

A software for three-dimensional visualization of magnetic lines that operates on tablet PCs using AR was developed, and practical lessons were conducted with eighth-grade middle school students. The results of the evaluation of the AR teaching aid using questionnaires show that the proposed teaching aid significantly improved students’ understanding of electromagnetism and enabled them to provide a scientific explanation of the phenomenon.

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