

Further Investigation of Examining Students Understanding of Lenz's law and Faraday's Law

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Abstract. Magnetic induction has been known to be a particularly difficult concept in introductory physics. In this project, we build upon our previous research on probing the difficulties students have with magnetic flux in regards to Lenz's Law and Faraday's Law. This presentation will explore student responses when the format of the instrument was reversed, so that students had to use a flux vs. time graph to infer details of the physical situation. Although the newer version of the survey identifies other difficulties students have, the student responses suggest the value of this reverse process in both probing student thinking and in instruction on magnetic flux.

Keywords: Electricity & Magnetism, flux, induction, Faraday's law, student understanding, physics education research.

PACS: 41.20.-z Understanding Faraday's Law and Lenz's Law

INTRODUCTION

We have been engaged in an ongoing study of student understanding of magnetic flux. One goal of this study is to develop an instrument that can be used by instructors in understanding the difficulties students face when trying to comprehend the key aspects of Faraday's Law and Lenz's Law. Previous work has shown that students can tend to rely on what is known as "common sense science" [1] to try to resolve issues with understanding certain naturally occurring phenomena associated with electromagnetism. We have explored the use of a graphical representation for certain physical situations to deepen student understanding of the underlying physics. Part of this investigation has been focused on establishing such a transition/representation that would both probe student understanding and serve as an instructional tool.

Work by Scaife and Heckler [2] showed that the representation of magnetic flux problems can influence student responses. Because of the complexity of the situation, magnetic flux is usually presented in problems verbally. There is really no common physical representation of magnetic flux that can help students "distinguish field from flux and to visualize changes in flux, especially in instantaneous changes" [3]. The derivative relationship between flux and EMF is reminiscent of the relationship between kinematic quantities, for which graphical representations have become an important instructional mode.

Graphs in general contain large amounts of data that can be inferred for analysis when it comes to trying to understand a certain physical situation. Graphical representations are often used as a "second language" [4] by physics teachers to help students learn difficult concepts. However, despite the power of graphs for depicting quantities that vary with time, most texts do not ask students to draw or interpret graphs of magnetic flux vs. time. We intend to investigate the extent to which such graphical interpretations can be useful if incorporated in classroom instruction.

In previous research, we found that when students were asked to draw flux and EMF vs. time graphs, they tended to draw the same graph for both quantities, suggesting that students did not fully understand the difference between flux and change of flux. This type of response is also reminiscent of common student responses to problems involving kinematics graphs, and further suggests difficulties in using the derivative relationship. Some student responses suggested a preferential association between flux and velocity regardless of the physical situation. Ultimately, it was found that students still had difficulties understanding Faraday's and Lenz's Law.

In this part of our research, we revised the written problems in our previously constructed instrument [5] in order to resolve some of the unanswered questions. In particular, we asked students to 'reverse the reasoning' [6] and modified several tasks in order to distinguish between potentially correct and incorrect responses.

CONTEXT FOR RESEARCH

Our study sample consisted of students in two levels of introductory physics courses at California State University Fullerton. The first course, described as Algebra-Based (AB), is designed for life science majors. The second, described as Calculus-Based (CB), is designed for those majoring in the physical sciences, math, or engineering. Each class is typically a traditional lecture with 30 to 100 students. Our sample includes three sections of each course, with $N=130$ and 135 students, respectively. We were particularly interested in comparing responses from the AB and CB courses.

In designing the initial instrument, we referenced a standard physics textbook [7], altering some of the textbook's problems on magnetic flux from quantitative to conceptual problems. The instrument was constructed to be appropriate for AB and CB sections (e.g., no references to derivatives). It was typically given after classroom instruction on the target topic as an in-class ungraded extra credit quiz for fifteen minutes. The written instrument was also used as the basis of a multiple choice online version (not reported here) and for several ($N=5$) individual student interviews with volunteers selected from the two courses.

The instrument includes several free-response questions that explore student thinking. (See Appendix for the version of the instrument reported in the current paper.) The problems require that the students relate a physical situation to graphs of flux vs. time and EMF vs. time. In addition, students are asked to describe the direction of induced current flow.

After the instrument was administered, we classified and coded student responses and entered the answers and explanations for each question into a spreadsheet. Most answers were clearly stated and readily categorized, but the authors examined several examples of student answers and reasoning to agree upon criteria for classification. Graphical responses were more difficult to analyze, but were characterized based on the shape and sign of the graph and its slope, as well as the value at important points (e.g., whether the initial flux was nonzero at $t=0$ in part 2A). Student response patterns were then analyzed.

RESULTS AND DISCUSSION

A summary of the percentage of correct responses to each question is shown in Figure 1. In comparing performance of students in AB and CB classes, we found that in most cases the students in the CB course had slightly more correct answers, as expected, but the difference was small ($\leq 10\%$). Most of the remaining

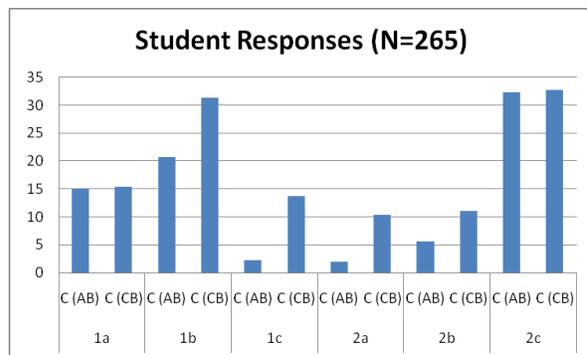


Figure 1. Percentages of correct (C) responses for each part of the instrument for AB and CB.

students answered incorrectly, though there were a few blank or unclassifiable responses in each case. Below we describe common response patterns and examine trends. For the sake of brevity, we do not examine all part of the quiz, but focus on those that illustrate students' ability to reason with the graphical representation of flux vs. time and EMF vs. time.

For Part 1a, students were asked to construct a shape that would best correspond to the flux vs. time graph given and to describe the motion of that loop at a given instant ($t=3$) shown on the graph (see Appendix). For the flux to change at a constant rate, the simplest answer involves a square or rectangular loop moving at constant speed. However, only a handful of students gave this response. Most students responded that the loop should be a circle or triangle. The written responses did not provide much insight into why students made these choices, but there was some suggestion that the triangular shape was chosen by students because of its similarity to the shape of the graph itself. In the interviews, when students were questioned about this problem, 4 of the students stated that any shape was possible, but that the circle "felt more like a logical answer." When asked why they had chosen a circle, one student stated, "it has to be a loop, so cannot be a square."

In responses about the motion of the loop, students tended to relate velocity of the loop directly to the flux vs. time graph. Only a few of students overall answered that the velocity would be increasing in order to be consistent with the flux vs. time given. Most of the students answered that the speed would be constant (37% for CB and 28% for AB) or that it would be decreasing (40% for CB and 47% for AB). There is some suggestion that student responses were linked to their interpretation of kinematics graphs; these answers would be correct for position vs. time or velocity vs. time graphs, respectively. In an interview, one student stated that "the straightness of the line on the curve" led to the conclusion that velocity was

constant, adding, “a curved segment on the graph would imply a different velocity.”

In Part 1c, the students are asked to construct a graph of EMF vs. time given the flux vs. time graph (see Appendix). As previously noted, this part was intended to probe student understanding of the derivative relationship between flux and EMF. As with most parts of the instrument, only a small fraction of students answered correctly. The most common incorrect answer (about 26% for CB and 30% for AB) was to draw a graph very similar to the flux vs. time graph. (Included in this category are identical graphs, but also graphs that have the same shape but opposite sign, or are shifted or magnified compared to the flux vs. time graph.)

We anticipated that the students in the AB and CB courses might answer this question differently. The CB students are taught this relationship in terms of derivatives and have a stronger math background. However, only 10% of the students in the CB course answered correctly. While the rate is higher than the rate in the AB course (under 2%), there is very little evidence of calculus understanding in either group.

In one of our interviews, a student initially drew an EMF vs. time graph identical to her flux vs. time graph, stating that “emf is a function of flux over time.” The student made clear that she was not confident in her response, immediately stating that “it is kind of an abstract concept to me.” However, as she explained her reasoning, she restated that “emf is the *change* in flux,” emphasizing the word change, and that “if we are talking about change in flux, it is not just flux, as a function, it is not flux over time, it is change of flux over time.” The student then redrew the graph correctly, though she was still not comfortable with the correct center line segment that she drew and stated that it “may not be correct.”

In Part 2a, the students were asked to construct a flux vs. time graph given a certain physical situation that is similar to many standard textbook problems (see Appendix). We constructed this problem to be different from the standard textbook version, in which the rails are parallel, based on results from an earlier version of the instrument. In the previous version, many students gave a largely correct answer (flux vs. time increasing linearly) but with reasoning suggesting an association of flux with speed. In this version, because the rails are not parallel, a correct graph would be curved and concave up. Student responses to the new version suggest that this change helped to distinguish between correct and incorrect thinking. A large fraction of students (38% for CB and 39% for AB) drew straight lines and stated that velocity was constant to support their reasoning. As in Part 1c, it seems that when a student does not understand the importance of area with respect to magnetic flux, there

is a tendency to cue on whatever information is given (i.e. constant velocity of the rod in this case).

This tendency is also apparent in student responses to part 2c. Given the same physical situation, students were asked to determine if the current in the rod was increasing, decreasing, constant, or zero. Our own previous research suggests that students related the speed of the rod to the amount of current flowing in the rod, which is correct with parallel rods. After revising the problem with non-parallel rods, many students still predicted that the current would be constant (about 34% for CB and 30% for AB), with many explicitly relating speed to current. Three students gave similar responses in interviews, but did not give a deeper explanation than a simple association of current with speed.

SUMMARY

This survey tests students’ ability to successfully use a graphical representation in a certain physical situation, as well as to apply a set of ideas that are associated with Faraday’s Law and Lenz’s Law. Although most of the students did not perform well in the survey, we believe there is value in the graphical representations of flux vs. time and EMF vs. time. Our discussions with students during and after the interviews in particular support our belief. Magnetic flux, EMF, and the relationship between them tend to be very abstract ideas that are very challenging for students. In the interviews, several of the students indicated that the graphical representation was useful to them in helping to visualize these quantities and their relationships. One student stated that “This challenge’s me into actually thinking about it as a function, not just plug and chug with numbers” and that “it adds another dimension of understanding”. Most of the students brought up their previous experience with similar representations from kinematics.

The representation seems to have value as a research task, but we further feel that it is a potentially valuable instructional tool. Our results as well as those from previous research suggest that many students develop very little in the way of intuition or conceptual understanding of these ideas. Several of the course instructors, particularly in the AB course, have stated to us that they spent very little time on Faraday’s law, and students confirmed that they had very little beyond a few equations to go on. It seems reasonable to call upon the experience students have with kinematics graphs, and use a graphical representation to supplement symbolic and verbal ones, in order to improve student understanding of this topic. Some caution is necessary, however, as our

results do suggest that students struggle with some of the same issues with these graphs as they do with kinematics graphs. We plan to use these results and those from previous versions to refine the survey items for potential instructional applications.

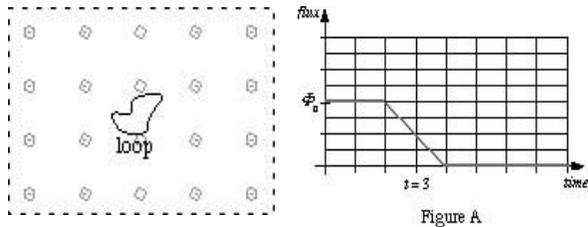
ACKNOWLEDGMENTS

This work is supported in part by CSUF Louise Stokes Alliance for Minority Participation grant, NSF HRD-0802628, and by the McNair Scholars program. I would like to thank all the professors who administered the survey to their students and to the students who took the survey as well. Thanks also to Dr. Leith Allen for her support throughout the project.

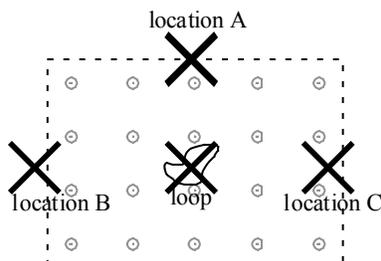
APPENDIX

1A. Consider a region of space. Within the dotted box, there is a uniform magnetic field pointing out of the paper. Outside the box, the magnetic field is zero. Imagine that you are given a conducting piece of wire. You can bend the wire into a closed loop of any shape (a generic shape is shown as an example.) The loop starts at the center of the field and moves in a way that produces the graph of magnetic flux vs. time shown in Figure A. (The initial flux Φ_0 at $t = 0$ is indicated, as is $t = 3$.) Into what shape could the loop be bent to produce the graph shown?

At $t=3$, is the loop moving with constant speed, with increasing speed, or with decreasing speed? Explain.



1B. This question again refers to the figures shown. Which location of the loop (shown with an X) is consistent with the graph at $t = 3$?

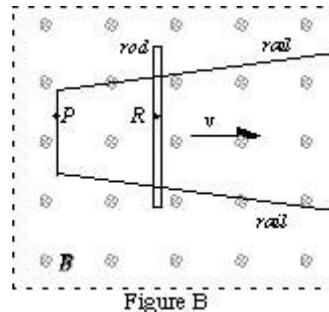


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1C. Sketch the graph of emf with respect to time in the same situation. Be sure that your graph is consistent with the graph of flux shown above.

2A. A circuit consists of two conducting rails connected by a wire, as shown in Figure B. A conducting rod slides along the rails at constant speed, and the whole circuit is in a constant, uniform magnetic field B pointing into the page. Assuming the bar is pulled to the right with constant speed, sketch a graph of the magnetic flux with respect to time. (You may assume that the rails extend well beyond the region shown.)



2B. In the situation described in Figure B, what is the direction of the current at points P and R? Explain how you arrived at your answer.

2C. As the rod moves to the right in figure B, is the current in the rod increasing, decreasing, constant, or zero? (You may wish to use the graph you drew above.) Explain briefly.