The Effect of Field Representation on Student Responses to Magnetic Force Questions

Thomas M. Scaife and Andrew F. Heckler

The Ohio State University, Department of Physics, 191 West Woodruff Avenue, Columbus, Ohio 43210

Abstract. We examine student understanding of the magnetic force exerted on a charged particle and report three findings from a series of tests administered to introductory physics students. First, we expand on previous findings that many students believe in “charged” magnetic poles and find that although students may answer according to a model where a positive charge is attracted to a south pole and repulsed by a north, these students may not believe that the poles are charged. Additional models produce identical answer schemes, the primary being magnetic force parallel to magnetic field. Second, the representation format affects responses: students answer differently when the magnetic field is portrayed by a field source vs. by field lines. Third, after traditional instruction improvement in student performance is greater on questions portraying field lines than for questions portraying field sources.

Keywords: Physics Education Research, Magnetic Fields, Student Models, Lorentz Force
PACS: 01.40.Fk, 01.40.gf, 01.40.Ha, 01.50.Kw

INTRODUCTION

There are many similarities between the electric force and the magnetic force on a charged particle. Ultimately, the concept of field, which could be represented by a source (e.g. charged plates, magnetic poles, etc.), by field lines, or both, must applied to properly determine the force for any given situation. In addition, both fields have two types of sources, positive/negative charge for an electric field or north/south pole for a magnetic field. Because of these similarities, it may be natural for the novice to assume that there is effectively no difference between determining the electric and magnetic force on a particle. This ambiguity may at least in part be responsible for the common misconception, first studied by Maloney, that a magnetic pole exerts a force on a charged particle, regardless of its velocity. In other words, Maloney concluded that some students interpret magnetic poles as being charged, thus affecting electric charge [1].

Maloney’s finding that many students answer according to a “charged pole” model raises several questions. First, the concept of charge and the concept of field are distinct; since the concept of field is an ultimate goal and necessary for eventual complete understanding, to what extent are students thinking about charges and/or fields when asked these force questions? Second, how sensitive are the student responses to representation? For example, if instead of being presented with poles, the students were presented with a representation of the field only, would the students still apply the “charged pole” model? If so, are they envisioning charges as sources of the fields and then making conclusions based on the presence of charges, or are they simply attending to the field alone and answering directly from knowledge of the field [2-4]? The effects of representation on student performance are the subject of many other studies (e.g. Meltzer in ref. 5). Maloney’s study does not examine the distinction between student understanding of charge and field, nor do the questions posed represent field lines.

To gain more insight into student understanding of magnetic forces, we expand upon Maloney’s findings by examining the effect of representation, i.e. poles or field lines, on student responses to magnetic force questions. We also include both a pre and post assessment to determine the effects of traditional instruction.

EXPERIMENT 1

The students in this experiment (N=122) were enrolled in the second of a three-quarter introductory, calculus-based physics sequence at The Ohio State University, a large research university. Instruction in the course was traditional. Short, multiple choice quizzes were administered during weekly lab meetings

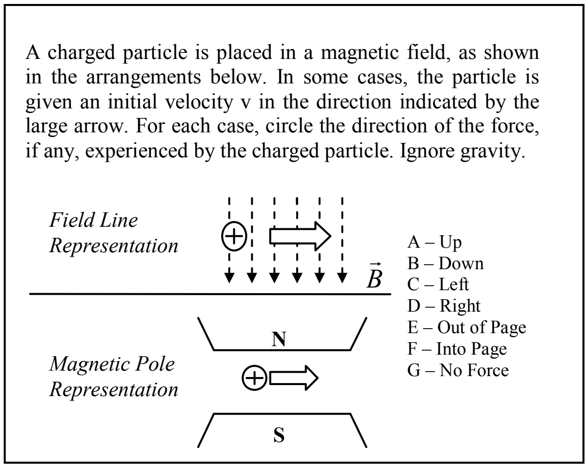

FIGURE 1. Example question from pre-test. Each student was given either the *Field Line Representation, or the Magnetic Pole Representation.*

and graded for participation. All questions asked were similar to those of the Maloney study – students were given a positively charged particle either moving perpendicular to the magnetic field or with zero velocity [1]. However the questions included two significant differences. First, the answer choices included all three dimensions. In Maloney's study, answer choices were limited to directions collinear with the field. In order to be correct, students had to repeatedly choose "neither" for all questions. This lack of directional choices potentially inflated responses in these directions. Second, in order to test the effects of representation format, approximately half of students were given questions in which the magnetic field was represented by magnetic poles, and the other half were given questions in which the magnetic field was represented by field lines. Examples of each question format are shown in Figure 1.

The pre-test was administered in the fifth week of a ten-week course, directly following instruction in electrostatics but previous to instruction in magnetostatics. Figure 2 presents students' answering patterns on both a non-zero velocity question and a zero velocity question. Both figures indicate that students in the field line representation condition are more likely to answer incorrectly, choosing "F Parallel to B" or "F Anti-Parallel to B". However, only the zero velocity question produces a statistically reliable difference between the conditions (t=2.25, dF=120, p<0.05), compared to the non-zero velocity condition (t=0.99, dF=120, p=0.32).

The post-test was administered in the 10th (final) week of instruction (N=124), about one week after the material was covered in class. There is a clear effect of instruction: 13% of the students obtained a correct answer in the pre-test compared to 45% in the post-test on the two reported questions. These results are somewhat different than Maloney's, who found that even after instruction approximately 60% of students answered according to the "charged pole" model [1]. Overall, students in the field line representation obtained higher scores than students in the pole representation on the 12-question quiz (field lines: $\bar{x}_f$=0.53, magnetic poles: $\bar{x}_m$=0.39, t=3.04, dF=122, p<0.01).

Figure 3 shows post-test results of questions virtually identical to the pre-test questions. On the post-test the performance of students in the two conditions reversed from the pre-test; students in the field line representation answer correctly significantly more than students in the pole representation in both the zero velocity (t=2.56, dF=122, p=0.01) and the non-zero velocity (t=2.69, dF=122, p<0.01) questions. Notably, students in the pole representation chose the answer consistent with the "charged pole" model more often than the student in the field line condition.

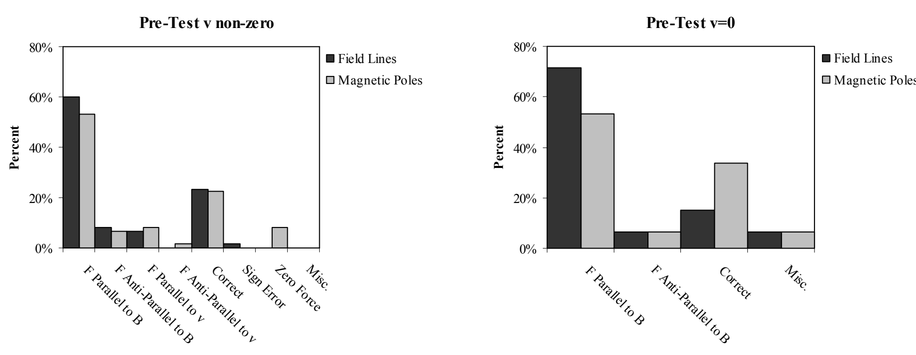

FIGURE 2. Plots of student responses to the non-zero and zero velocity pre-test questions (Field Line Representation: N=60, Magnetic Pole Representation: N=62).

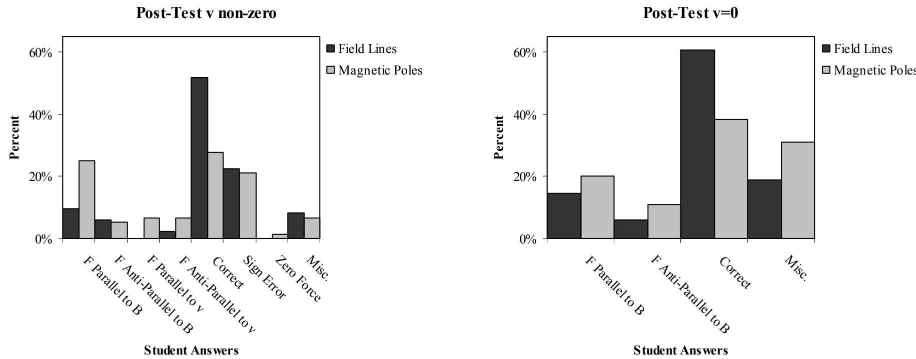

FIGURE 3. Plots of student responses to the non-zero and zero velocity post-test questions (Field Line Representation: N=69, Magnetic Pole Representation: N=55).

Discussion

The pre-test results suggest that when given a question represented with magnetic field lines, students with little prior knowledge of magnetic forces tend to answer that the magnetic force is in the direction of the field, similar to the rules for electric field lines, which they just learned in an earlier section in the course. Note that this answer scheme is not necessarily the same as that of the “charged pole” model, since there is no explicit representation of a pole. When students are given a question represented with magnetic poles, they tend to answer in a way consistent with a “charged pole” model. Although not directly tested in this experiment, students may be first imagining field lines from the represented poles and then using the field lines to answer. It is not unreasonable to infer from this data that in fact these two different representations are cueing two completely different models: either the “charged pole” model or the “force-in-direction-of-field” model.

The post-test results present an interesting shift in the dependence of representation: when students are presented with the field representation they appear to have abandoned the “force-in-direction-of-field” model and learned the correct model, whereas the when cued with the pole representation, many students still answer according to the “charged pole” model, even after traditional instruction (although less than before instruction). Nonetheless, these results are only suggestive; it is still not clear whether students are using any particular model.

EXPERIMENT 2

Experiment 2 was administered to a separate but similar population of students (N=239) in a different quarter. Experiment 1 indicated that when compared between students in different conditions, student answering depends on the representation format of the question, namely field lines or poles. In Experiment 2, we administer a within-student test to determine whether the same student will answer differently when presented with the two representations. In order to account for effects of order of presentation of the two representations, one half of the class received one representation first and the second half received the other first.

Results indicate that while student performance did not depend significantly on question order (field line question: χ^2=4.47, *dF*=2, *p*=0.11; magnetic pole question: χ^2=1.34, *dF*=2, *p*=0.51), students did answer according to the “charged pole” model more frequently to the field line representation (67% compared to 57%) (McNemar’s test, χ^2=6.7, *dF*=1, *p*=0.01). Figure 4 shows student responses to the both the magnetic pole representation and the field line representation. The “Charged Pole” category includes all responses in the dimension of the magnetic field, including parallel and anti-parallel, while the “Correct” category includes all responses in the dimension of the correct answer.

The post-test was administered under somewhat different conditions than in Experiment 1, namely in the 9th week, which was during (i.e. essentially directly after) instruction of the Lorentz force and the right hand rule. In addition, this post-test was graded for credit. Again, question order did not affect student performance (field line question: χ^2=0.63, *dF*=2, *p*=0.73; magnetic pole question: χ^2=0.67, *dF*=2, *p*=0.72).

As in Experiment 1, students in the post-test answer according to the “charged pole” model slightly more frequently to the magnetic pole representation (8% compared to 5%) (McNemar’s test, χ^2=2.6,

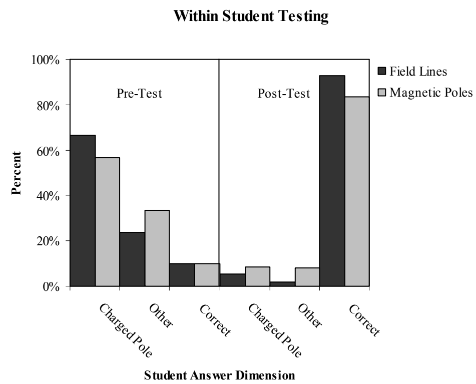

FIGURE 4. Plot of within student responses to the non-zero velocity pre-test questions (N=239) and post-test questions (N=225).

p=0.17), and answer correctly more frequently to the field line representation (93% compared to 84%) (McNemar's test, χ^2=13.3, dF=1, p<0.001). Figure 4 shows student responses to the both the magnetic pole representation and the field line representation.

Discussion

The results from the Experiment 2 replicate the results of Experiment 1 in a within-subject design. Most notably, the same student will answer differently to magnetic pole and field line representations, and traditional instruction tends to affect the student responses to field line representation more than responses to magnetic pole representation.

CONCLUSIONS

There are two primary conclusions to be drawn from this study. First, we replicate and the findings of Maloney [1], which claim that many students answer in accordance with a "charged pole" model, and extend these results to include the field line representation. In the "charged pole" model, students believe that charged particles experience magnetic forces directed toward or away from poles and/or along field lines, much like the electrostatic force. While traditional instruction reduces the occurrence of this incorrect conception, our findings suggest that the difficulty persists in a significant number of students.

Second, our data demonstrate that the representation format of a question significantly affects students' correct determination of the direction of magnetic force on a charged particle. Following traditional instruction, students answer the magnetic field line questions more correctly than the magnetic pole questions, suggesting that the different representations tested cue different solution paths or models. One possible solution path, which is consistent with our data, is that when students are presented with the relatively abstract representation of field lines, they easily apply the right hand rule, which explicitly refers to the magnetic field, as taught in class. Conversely, when presented with magnetic poles students might take one of several different paths. The relatively concrete representation of the poles could lead many students to choose an answer consistent the "charged pole" model. Alternatively, students may first use the magnetic poles to draw the magnetic field and then apply the right hand rule to determine the direction of the force. This additional step of drawing the field introduces some degree of error. Many students did, in fact, spontaneously draw field lines when presented with the magnetic poles representation.

An additional explanation for the difference between student performances in differing representations is that in the course of traditional instruction, field line representation tends to be favored by the instructor, thus providing the students with a greater degree of practice and familiarity. Nonetheless, even if this explanation is the primary reason for the difference in performance, our results clearly demonstrate that instruction in one representation alone is not sufficient to ensure complete comprehension of a concept. Instead, these results reveal that students will resort to preconceived notions—or an altogether different model—whenever confronted by a different context.

ACKNOWLEDGMENTS

This research is supported by a grant from the Institute of Educational Sciences of the U.S. Department of Education (#R305H050125).

REFERENCES

1. D. P. Maloney, "Charged poles?" *Phys. Educ.* **20**, 310-316 (1985).
2. J. Guisasola, J. M. Almudi, and J. L. Zubimendi, "Difficulties in Learning the Introductory Magnetic Field Theory in the First Years of University," *Sci. Ed.* **88**, 443-464.
3. M. C. Pocovi, "The Effects of a History-Based Instructional Material on the Students' Understanding of Field Lines," *J. Res. Sci. Teach.* **44**, 107-132.
4. S. Tornkvist, K. A. Pettersson, and G. Transtromer, "Confusion by representation: On student's comprehension of the electric field concept," *Am. J. Phys.* **61**(4), 335-338.
5. D. E. Meltzer, "Relation between students' problem-solving performance and representational format," *Am. J. Phys*. **73**(5), 463-478.