Students' understanding on questions of electric and magnetic interactions represented with similar surface features

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Abstract. In electricity and magnetism, there is a certain degree of relation given by the symmetry in Maxwell's equations. Our objective is to explore students' understanding of electricity and magnetism, in questions represented with similar surface features. We created an open-ended questionnaire with 9 items about electricity and their magnetism counterpart. We applied the instrument to 322 engineering students taking the course of electricity and magnetism. We present the results about electric and magnetic interactions. We conclude that there are differences in students' understanding between electricity and magnetism, and that some difficulties persist. Teachers could benefit from learning these difficulties.

1 Introduction

To promote conceptual understanding, we need to identify the most common difficulties that students have in physics and address them through the development of concepts, reasoning ability and representational skills [1]. When solving problems of physics, novices tend to focus on the surface features of the representation, while experts focus on the underlying principles [2]. It is relevant to study students' understanding in electricity and magnetism because this course is taught in engineering programs in most universities at an introductory level. In electricity and magnetism, there is a certain degree of relation given by the symmetry in Maxwell's equations. Isomorphism [3] is mostly related to the surface features of the representation (e.g. the form of the mathematical expressions), and to the underlying principles (e.g. the superposition principle), rather than to the meaning of the electric and magnetic concepts.

The reasoning process to solve isomorphic electricity and magnetism problems is not necessarily the same, but is related through representational skills and underlying principles. For example, to identify the interaction between two positive charges, you need to identify the direction of the force on each charge due to the other one, which is in the direction of the electric field; similarly, to determine the interaction between two cables with outward electric currents, you need to identify the direction of the force on each cable due to the other one, which is in a perpendicular direction to the current and the magnetic field.

In physics education research, students' understanding on isomorphic problems has been studied in different topics, but little work has been done in electricity and magnetism. Scaife and Heckler analyzed interference between electricity and magnetism problems [4]. In our research group, we have explored isomorphism in other topics [3]. The objective of our broader study is to continue exploring isomorphism in electricity and magnetism with the research question: How do isomorphic surface features affect students' understanding of electricity and magnetism? In this abstract we only analyze students' understanding of electric and magnetic interactions between two positive charges or two outward currents, respectively.

2 Methodology

The objective of this study is to explore how isomorphic surface features of problems affect student understanding of electric and magnetic interactions through a qualitative approach. The study was conducted in a private Mexican university with 322 engineering students taking the calculus-based course of electricity and magnetism during the spring semester of 2017. The course consists of three hours of lecture class and 1.5 hours of laboratory session per week. We administered two versions of a test after instruction, randomly to all students.

We created an open-ended questionnaire with isomorphic surface features, partially based on the Conceptual Survey of Electricity and Magnetism (CSEM) [5] and on the test reported by Scaife and Heckler [4]. We picked as the main topics for the test: sources of field (charges VS currents), interactions (electric VS magnetic), superposition (electric field VS magnetic field), and force on a charge due to a field (electric VS magnetic). In order to avoid students' awareness of the isomorphism, we divided the topics into two versions of the test, as shown in Table 1.

Table 1. Division of topics into two versions of the test

Items	Version 1 (electricity)	Version 2 (magnetism)
1	Charges as sources of electric field	Currents as sources of magnetic field
2, 3, 4	Interactions between charges	Interactions between currents
5	Superposition of electric field	Superposition of magnetic field
6, 7, 8, 9	Charge in a uniform electric field	Charge in a uniform magnetic field

3 Results and conclusion

In this study, we present results on questions 2 and 4. In question 2 of version 1, students are presented with two identical positive charges (+q) and are asked to describe the interaction, if any, and to explain their reasoning. In version 2, they are presented with two cables with electrical currents pointing outward (⨀I) and are asked the same. In question 2 of version 1, 95% of students were able to identify that there is repulsion between the charges, which is correct. In question 2 of version 2, the correct answer is that there is attraction between the two cables, but only 27% of students were able to arrive to this conclusion. The most common mistake was to state that there is repulsion (30%), which could mean that students memorize that charges of the same sign repel each other and apply this reasoning to electric currents.

In question 4 of version 1, students are presented with two positive charges (+q and +3q) and are asked to compare the magnitude of the force on each charge. In version 2, they are presented with two cables with electrical currents pointing outward (⨀I and ⨀3I) and are asked the same. In both versions, students had difficulties to state that the forces are equal (22% in version 1 and 18% in version 2), indicating that this difficulty is persistent regardless of the isomorphic surface features of the representation.

From these results we can conclude that there are differences in students' understanding between electricity and magnetism, and that some difficulties persist. Learning about these tendencies and difficulties, could be useful for instructors teaching these topics. This is part of a broader study where we aim to create a standardized multiple-choice isomorphic test of electricity and magnetism. So far, we are on the first stage of the process, we created an open-ended questionnaire that will give us information about students' more common difficulties to design the multiple-choice test, as recommended in [5].

References

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