Contrasting Students' Understanding of Electric Field and Electric Force

Alejandro Garza and Genaro Zavala

Physics Education Research and Innovation Group
Department of Physics, Tecnologico de Monterrey, Campus Monterrey,
E. Garza Sada 2501, Monterrey, N. L. 64849 Mexico

Abstract. Students may have greater difficulties in understanding electric interactions because they have less day to day experience with them than with mechanics. There may also be differences in understanding of different electric concepts like electric force and field. This study presents the results of students' responses to two sequences of superposition principle isomorphic questions in which the only difference was that in one of the sequences, the electric force was used and in the other, the electric field. We administered one of the sequences to 249 students at a large private Mexican university after covering electrostatics in an Electricity and Magnetism class. The students' answers, reasoning and drawings were analyzed. We found that students who took the force sequence were better able to correctly answer the questions using the superposition principle than those students with the field sequence. The analysis of the students' reasoning and drawings helped us to examine their understanding of electric field and the use of electric field lines.

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INTRODUCTION

There are two ways in which electric interactions are commonly represented. The first is through the electric field which describes how bodies interact due to their electrical properties. The second one is by using the electric forces of the interaction in question. In Electricity and Magnetism (EM), students have difficulty understanding and applying these concepts [1, 2]. It seems reasonable that students limited experience with the effects of electric forces at a distance (outside of electric shocks or the effect of taking off a charged sweater) that they would struggle with these concepts. Yet, in an attempt to make the concepts more familiar, students use known models to describe these interactions, i.e., the use of a Newtonian model for describing the interactions [3].

The mental models that students have on a concept directly affect how they perform when trying to solve problems related to these concepts. A good model lets students solve problems in a competent way while poor models may lead to a trial and error approach [4]. One example of a poor model is that students usually assign a physical nature to the electric field lines, rather than taking them as mathematical abstractions that represent characteristics of a vector space [5].

Since the models of electric force and electric field that students have available directly affects their ability to answer the same question presented in a different way, this paper attempts to understand the differences in understanding among students using two different concepts: electric force and electric field.

Therefore, our objectives are: 1) to compare students' responses on electric field questions to those on electric force questions, and 2) to analyze the types of drawings students use to represent the electric field.

The study is divided into three sections. The first part describes the methodology, which explains how the experiments were conducted. The second addresses the results and discussion. Finally, a summary of the work and final comments are presented.

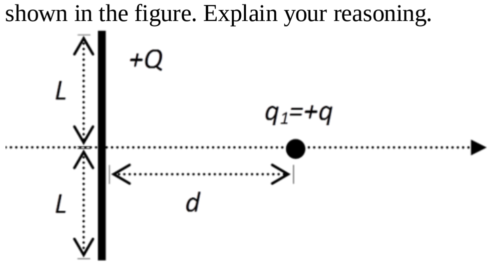
METHODOLOGY

This research was conducted at a large private Mexican university with engineering students taking their final required physics course (after two previous physics courses), Electricity and Magnetism, in a sophomore year. The research was carried out after the topic of electrostatics had been presented in class. The testing was done using open-ended questions which required the student to supply an answer, a drawing and the reasoning behind it. Two different versions of question sequences were answered by similar populations of students chosen at random following the methodology used by Barniol & Zavala [6]. Students come from different sections with six different instructors. The questions were administered in Spanish.

Each sequence administered consisted of two questions, as presented in Figure 1. The purpose of the first question was to serve as an introduction to the sequence, while that of the second was to analyze students' understanding of the superposition principle when in the presence of different charge distributions. The structure of both sequences was the same. The only difference is that the first sequence asked students to compare the force on a point charge due to the other charges. In the second sequence, there was not a point charge, there was a point in space in the same position, and the question asked for the electric field at that point. These sequences were designed by the authors. They were validated in content by physics instructors and a pilot of students validated that what we wanted to ask was what they really understood.

The sequence containing electric force will be addressed as FS or electric force sequence; it was administered to 122 students. The electric field sequence will be referred to ES; it was administered to 127 different students. The answers were recorded and reasoning of students were qualitatively analyzed and categorized according to the results [7].

FS sequence:
Question 1. There is a bar of length 2*L* with a uniformly distributed charge of +*Q*. Draw on the figure and describe the electric force on the point charge $q_1=+q$ that lies at a distance d to the right of the center of the bar, as shown in the figure. Explain your reasoning.



Question 2. A point charge of value +Q is placed at a distance d to the left of the bar as shown in the figure. Draw on the figure and describe the electric force on the point charge q1. How do the magnitude and direction of the electric force change compared to Question 1? Explain your reasoning.

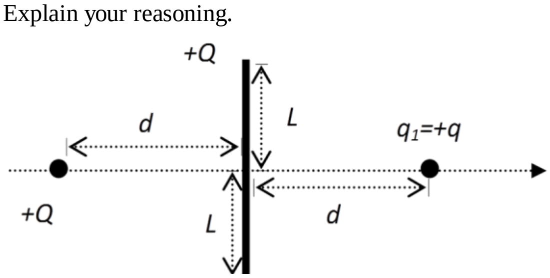


FIGURE 1. Questions regarding the electric force due to a uniformly distributed charge. The second sequence is not presented. Instead of having a point charge +*q*, there was a point in space at the same position and students were asked for the electric field.

RESULTS AND DISCUSSION

In previous studies regarding problems with the concept of electric field, we have found that students have trouble answering questions in these domains [8]. Yet, we have no evidence as to whether the problems with the superposition principle are related more to the electric field concept than to the electric force concept. Moreover, we wanted to more fully understand the models of each concept that were being used by the students.

In the first section we analyze the differences in answers when the students were asked the same questions with two different concepts. The second subsection analyzes the drawings students used.

1. Comparison of Electric Field/Force Concept Answers

Table 1 presents the results of question 2 for each sequence. Only the two main answers are presented with their respective reasoning. As can be seen, there is a significant difference between the answers to question 2, whether the electric field or force is involved, when compared to question 1. While 70% of the students responded correctly to the question on FS, only 54% did so on the ES question. The most common incorrect answer, *the field does not change*, goes from 17% in FS to 26% in ES. At a first glance, this result indicates that there is a problem with the understanding of the electric force, and an even greater one regarding the field concept.

TABLE 1. Results of question 2 in both tests: FS and ES. The two main reasonings are included. At each column, the first number represents the answer and the offset numbers the reasoning.

Answer/reasoning	FS		ES	
Electric Force/Field increases	70%		54%	
Superposition principle		48%		35%
The charge increases		31%		26%
No reasoning given		20%		36%
Electric Force/Field is the same	17%		26%	
E-field is cancelled		0%		21%
The point charge does not contribute		14%		24%
No reasoning given		52%		27%

Reviewing the reasoning of the correct answers, we can see that not all the students are explicitly using the *superposition principle*. In FS only 48% of those who answered correctly were using it. 31% used the simple reasoning that *more charge yields more force,* which could mean that they are referring to the superposition principle. In the ES, 35% of those who answered correctly used the *superposition principle* explicitly, while 26% used the *more charge yields more field* reasoning. If we add up the *superposition principle* reasoning and the *more charge yields more force* reasoning for the FS and do the corresponding calculation with the ES, we have 79% versus 61%. This is further evidence that the electric field concept is less understood than force concept.

On the other hand, among those who gave the most common incorrect answer in the FS, only 14% of the students supplied a formal reasoning: *the point charge does not contribute*. The remaining 86% either gave no reasoning or one that was completely unrelated to the subject. In the ES, from those giving the most common incorrect answer, 21% said that the field between the point charge and the bar was cancelled, hence there is no contribution to the charge, while 24% stated that the point charge does not contribute at all. From these results it can be seen that there should be, in the case of the electric field concept, another line of reasoning that the students are using but that is not explicit.

In order to further understand what students wanted to explain in their answers, the drawings they made with regard to both the electric field and the electric force were analyzed.

2. Analysis of Students' Drawings in the ES and FS

When analyzing open-ended questions, there can be many possible different answers and reasoning used by students. The same applies to the drawings they sketched to represent their ideas. Yet, there is some consistency as to how they view the electric force and field. In Figure 2, the most common drawings of the force vectors for question 1 are presented, while in Figure 3 those related to the electric field are presented.

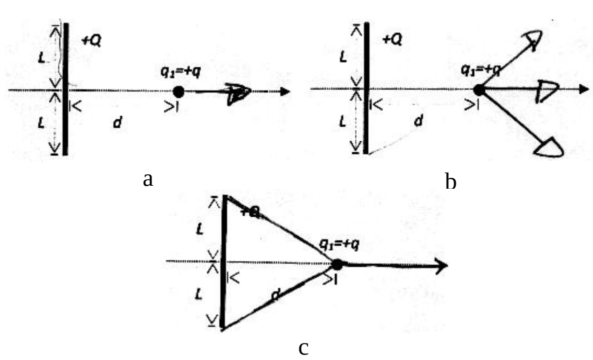


FIGURE 2. Most common drawings for question 1 in FS. 38% of the students drew ***a***, while 19% and 28% drew ***b*** and ***c*** respectively. For question 2, the most common drawing was the equivalent of ***a***, with 62%.

From the results of the drawings from the first question, it can be seen that although most students view the electric force as a vector, some students tend to use field lines to represent the electric force instead of treating it outright as a vector.

Observing the drawings in question 1 for ES in Figure 3, it is noted that students use field lines, some of them incorrect, to represent the field at point *P*. Not only that, they even seem to visualize it as generated from an infinite source, as can be seen in Figure 3. When representing the electric field, we found that 50% of the students (figure 3 **c** and **d** and the remaining 8%) use electric field lines instead of using the inherent vector properties of the field.

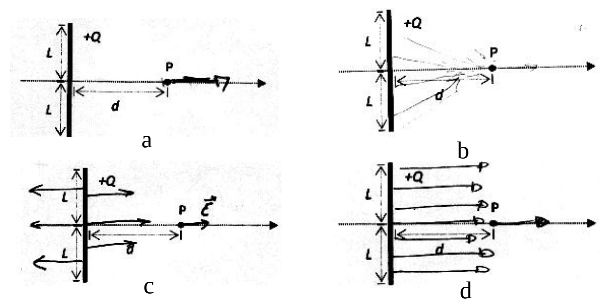


FIGURE 3. Most common drawings for question 1 in ES. 26% of students drew ***a***, while 24%, 14% and 28% drew ***b***, ***c*** and ***d*** respectively; 8% drew something else.

For question 2 of the FS, most students used a vector representation for the force in which 62% made a drawing similar to the one in Fig. 2-a. The drawings are not shown.

Figure 4 represents the drawings students used answering question 2 in the ES.

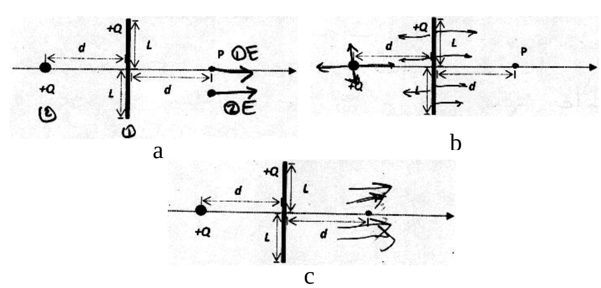


FIGURE 4. Most common drawings for question 2 in ES. 33% of students drew ***a***, while 17% and 16% drew ***b*** and ***c*** respectively.

The representation students used seems to be somewhat affected by an incorrect use of the superposition principle. As can be seen in Fig. 4-b, some students make drawings of the electric field lines both for the bar and the added electric charge without interaction, as if they were independent. Two different representations were found, one in which the field lines of the bar were present but only a vector from the added charged was drawn, and another in which the field lines of the charge were presented as if the bar did not exist, and vice versa. The types of drawing and the types of independent representation used are presented in Table 2.

TABLE 2. Drawings for the added charge in question 2 of the ES. Note that the field lines drawings present independent field lines for the bar.

Representation / Drawing	Only a vector	Field lines of the charge
Electric field as a vector	60%	20%
Field lines to both sides	30%	65%
Field lines only to the right	23%	62%

As can be seen in table 2, almost all students who used the electric field line representation for the bar ignored the effect of the field lines of the other charge (bar and added charge). This leads us to think that students are having trouble representing the electric field not only because of its abstraction, but because of the use of electric field lines.

To further explore this partial conclusion, in table 3 a comparison between the type of reasoning and the drawing used is presented.

TABLE 3. Results of question 2 in ES and the type of drawing used in each. The drawings are those presented in Figure 4. At each column, the first number represents the answer and the offset numbers the reasoning.

Drawing / Ans/reasoning	a		b		c	
Field increases	42%		13%		22%	
Superposition		45%		33%		20%
More charge		17%		22%		53%
Field is the same	24%		27%		9%	
It is cancelled		13%		33%		0%
Point charge		13%		33%		0%

Among the students that answered the second question correctly, 42% used a vector representation in their drawing. From those, 45% directly addressed the superposition principle. Meanwhile, among those that gave the most common incorrect answer, only 24% of them used the vector representation. Although the drawings of those that answered incorrectly are more diverse, 64% used electric field lines representations (100% minus 24% who used vectors, 6% who made no drawing and 6% other drawings).

By analyzing only the drawings, and now taking into account the answers and reasoning, it seems clear that in general those students that could not correctly answer the question used a model based on electric field lines. Meanwhile those that answered it correctly used a model based on vectors. This becomes more clear when taking into account the answers and drawings from the FS, where most students used a similar model.

SUMMARY

This report is part of a preliminary study on the understanding of electric field. The most important findings with this population are:

- Students have a much harder time understanding the electric field concept than the electric force concept.
- Those students who can answer correctly use mostly vector-based models.
- Most students use electric field lines to represent electric fields, instead of treating them as vectors.
- Most students do not understand the electric field lines concept, since they treat them as independent from one object to another.

Further research is currently underway to continue to study the level of students' understanding of the electric field concept.

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