

Electric Field Concept: Effect of the Context and the Type of Questions

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Abstract. We administered several open-ended questions to students after electrostatics is covered in an electricity and magnetism class at a private Mexican university. In the first part, the objective is to compare students' responses on electric field concept questions in the presence of charges and conductors to those in the presence of charges and insulators. In the second part, the objective is to analyze the difference in responses when the context is changed. This report compares students' answers to electric field concept questions while changing from abstract objects, i.e., point charge, non-conducting sphere; to already-used real materials in lab, i.e., charged tape, non-conducting pencil. Lastly, the objective is to analyze whether a guided question helps students to better answer electric field questions. This study compares students' responses to electric field concept questions with no guidance to responses to guided questions and the degree of guidance.

Keywords: Electric field, Conductors, non-conductors, context, guided questions

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INTRODUCTION

The electric field which describes how bodies interact due to their electrical properties is a concept which Electricity and Magnetism (EM) students have more difficulty to understand [1]. This is expected because; unlike in mechanics in which students have interacted with concepts seen in class, in EM students have less experience making the topic more abstract.

However, having no prior knowledge of these interactions, students look for a familiar model to interpret what is seen in class leading them to use a Newtonian model for describing the interactions. For instance, bringing a charge close to another, a force is exerted between them, making students to understand force but not helping them to acquire the electric field concept [2].

Studies have shown that mental models that students have on a concept directly affects how students perform. If it is a good model, students are able to solve problems in a competent way. While those with a poor model use trial and error to solve problems [3]. One example of a poor model is that students usually give a physical nature to the electric field lines, rather than take them as mathematical abstractions that represent characteristics of a vector space [4].

This paper attempts to understand the models of electric field and electrical interactions that students have and how the influence of context or the type of questions can evoke more sophisticated models of

electric field and electrical interactions. Therefore, our objectives are: 1) to compare students' responses on electric field concept questions in the presence of charges and conductors to those in the presence of charges and insulators, 2) to analyze the difference in responses in which the context is changed, and 3) to investigate whether a guided question helps students to better analyze the phenomena, resulting in a better answer.

The work is divided into sections where the first part is the methodology which explains how the experiments were conducted. Then there are two subsections in the Results and Discussion session addressing the objectives. Finally, there is a concluding section in which there is a summary of the work and final comments.

METHODOLOGY

This research was conducted in a large private Mexican university. Since this is a preliminary study, only open-ended questions were used. Students who participated in this study are in their EM course in this institution. All questions were administered after the instruction of electrostatics.

Following the methodology used by Barniol & Zavala [5], we compare different versions of questions with populations of students chosen randomly. All the questions were administered in Spanish.

RESULTS AND DISCUSSION

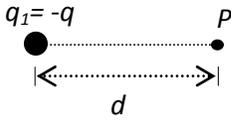
This section is divided into two subsections addressing two and one objective respectively.

1. Electric field due to abstract/lab-type conductors and non-conductors

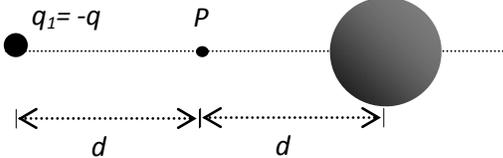
Before the experiment reported in this manuscript, we have had previous experience with students regarding the electric field concept. We had found, as also reported in this article, that students had difficulties on the electric field concept. However, we were unsure whether those difficulties were due to the electric field concept itself or the difficulty of using abstract items which might not mean anything to students. In our problems we used point charges and conducting spheres or non-conducting ones. In this part, besides identifying different difficulties in the interaction with conductors and insulators, we present results in which we used “real objects” in our wording.

The first sequence we administered to students was to explore students’ understanding of electric field. Fig. 1 shows a sequence of three problems which was administered to 143 students. This sequence will be called “complete sequence with abstract items”, CSAI.

First sequence:



Question 1. There is a point charge $q_1 = -q$ at a distance d from point P as shown in the figure. Draw on the figure and describe the electric field at point P . Explain your reasoning.



Question 2. A neutral conducting sphere is placed at a distance d from point P as shown in the figure. Draw on the figure and describe the electric field at point P . How does the magnitude and direction of the electric field change at point P compared to Question 1? Explain your reasoning.

Question 3. Note: question 3 is the same as question 2 but replacing the conducting sphere by a non-conducting neutral sphere.

FIGURE 1. Questions to students regarding the electric field due to a point charge and how that field changes in the presence of a conducting and a non-conducting sphere.

A similar sequence consisted on the same questions as the first one but replacing abstract items (point

charge, conducting and non-conducting sphere) with objects students used in a previous lab (charged bar, conducting pith ball and a non-conducting pencil) following the structure of research-based educational materials [6] in which learning is based as much as possible with real-life experience materials. This other sequence will be called “complete sequence with lab objects”, CSLO, and was administered to 152 students.

The first question was designed to act as introduction to the other two questions; however, interesting results were obtained with it. Table 1 presents the results.

Table 1. Results of question 1 in both tests: CSAI and CSLO. The two main reasonings are included.

Answer/reasoning	Test	
	CSAI	CSLO
E to the left	73%	47%
<i>E-field lines go to a negative charge</i>	57%	23%
<i>Coulomb's Law</i>	5%	5%
E field going into the charge	17%	42%
<i>E-field lines go to a negative charge</i>	9%	22%
<i>Coulomb's Law</i>	4%	3%

In CSAI, 73% of students draw the electric field at point P to the left and 17% of them draw arrows that finished on the point charge. From the 73% of the students who draw a correct vector, 57% (from total), mention electric field lines that “are going to a negative charge” as the reason of the electric field direction. This reasoning indicates us that students may have been remembering a fact instead of understanding the concept of electric field. A better indication of this is that analyzing the results of the same question for CSLO, we can see from Table 1 that in this case the percentage of students answering correctly decreases to 47% and those who draw line fields to the negatively charged bar increases from 17% to 42%. This result indicates that students based their answers to electric field questions using electric field lines, something which is clear that have not mastered yet. An example of reasoning of a student, who is answering correctly the question but his/her reasoning when he/she uses E-field lines is incorrect, is presented in Fig. 2.

The reasoning “Coulomb’s Law” could be a better reasoning than the one using E-field lines; however, interviews have to be made to prove this.

A very small number of students give an experimental reason mentioning the electric force that the negative charge would exert on a test charge if the test charge were placed at point P . We think that this is a correct explanation; however, not many students respond that way.

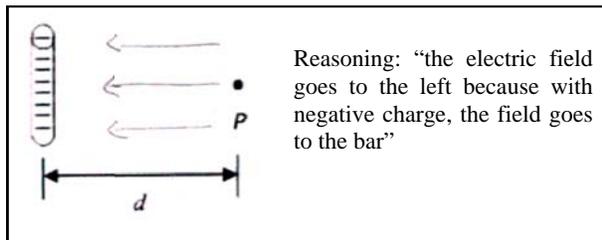


FIGURE 2. An example of reasoning to question 1 in the experimental test.

Table 2 shows the answers to question 2 on both tests. For each answer, the table contains the most important students' reasoning.

Table 2. Results of question 2 in both tests: point charge and the charged bar. The main reasoning is included.

Answer/reasoning	Test	CSAI	CSLO
E-field to the left increases		43%	39%
<i>Induction of charge producing an E-field</i>		36%	33%
E field does not change		29%	29%
<i>The sphere is neutral</i>		17%	16%
E-field changes		21%	24%
<i>Induction of charge</i>		8%	12%

As shown in Table 2, 43% of students correctly state that the electric field at point P is still to the left but greater in magnitude. 36% complete the correct answer with a correct reasoning; the rest 7% of students give other reasoning or not reasoning at all. There are 29% of students who think that the electric field is not changing despite the presence of the conducting sphere. Most of them reason that the sphere is neutral so no electric field will produce.

There is a large group of students (21%) whose answer is that the electric field changes but cannot say how it is changed. Many of them mention that there is an induce charge on the conductor but cannot determine what happens to the electric field.

Comparing these results to those in the CSLO test, we can see that using objects that they previously used in the lab does not improve students' results. The results in each of the categories are almost the same. There is a small decrease on the correct answer and an increase on the non-deterministic change answer but it is not probably statistical significant.

Table 3 shows the answers to question 3 on both tests. For each answer, the table contains the most important students' reasoning.

As shown in Table 3, only 9% of students answer the question correctly (7% with a correct reasoning).

79% of students think that the electric field is the same as before the non-conducting object was placed there.

As expected, most of the students who think that the electric field does not change think that a neutral non-conducting object will not produce an E-field.

Table 3. Results of question 3 in both tests: point charge and the charged bar. The main reasoning is included.

Answer/reasoning	Test	CSAI	CSLO
E-field to the left increases		9%	8%
<i>Polarization of object producing an E-field</i>		7%	2%
E field does not change		79%	80%
<i>The object is neutral</i>		52%	35%

Again, this table shows that using known objects instead of abstract items in the questions, does not produce any change in the type of reasoning. We decided to use real objects in the following tests just to be more consistent using real-life applications.

Comparing the results of table 2 with a conducting object to the results of table 3 with a non-conducting object, is evident that if the students have difficulty understanding induction of charge in conductors, they have even more difficulty understanding polarization. Since in both cases the superposition principle is needed to answer the question, the differences in results are an indication of the difference in difficulty of induction and polarization.

2. Effect of guidance

The first question we asked ourselves before doing this experiment was regarding understanding of the problem. We have asked students what happens when a conducting object is placed nearby of a charge. We expected students to answer that the external charge will induce charge in the conductor (making the electric field zero inside the conductor) and that the new distribution of charge in the conductor will be a new source of electric field taking the superposition principle into account. However, a small percentage of students did that. Of course, the previous section also indicates that the difficulty is more significant when an insulator is placed instead of a conductor.

Based on some Tutorials and its exercises [6], we tried to guide students to the right reasoning by asking a previous question before the electric field question (question 2 in Fig. 1). We designed three versions of a test: an original version (Original), a guided version (Guided) and an extended guided (E-guided). The questions (without images) are presented in Fig. 3.

Table 4 shows the results of the same question in the three versions, question 2 in the original version and question 3 in the other two versions.

Original version:**Question 1.** The same as question 1 in Fig. 1.**Question 2.** The same as question 2 in Fig. 1.**Question 3.** The same as question 3 in Fig. 1.**Guided version:****Question 1.** The same as question 1 in the original version.**Question 2.** (Showing the same figure as in question 2 in the original version). A conducting neutral sphere is placed at a distance d at the right of point P as shown in the figure. In the lab we saw that the conducting sphere was attracted to the charged bar. Why did that occur?**Question 3.** The same as question 2 in the original version.**Extended guided version:****Question 1.** The same as question 1 in the original version.**Question 2.** (Showing the same figure as in question 2 in the original version). A conducting neutral sphere is placed at a distance d at the right of point P as shown in the figure. In the lab we saw that the conducting sphere was attracted to the charged bar. Draw in the figure the distribution of charge on the sphere and explain why.**Question 3.** The same as question 2 in the original version.**FIGURE 3.** Three sequences administered to one third of students each randomly chosen.**Table 4.** Results of question: How does the electric field at point P change placing a conducting sphere? A direct question, after guiding student and a deeper Guinness. Answers and main reasonings are included.

Answer-reasoning\ Question	Original	Guided	Extended guided
E-field to the left increases	36%	52%	51%
<i>Induction of charge producing an E-field</i>	30%	39%	30%
E-field does not change	26%	25%	23%
<i>The sphere is neutral</i>	16%	13%	13%
E-field changes	22%	12%	17%
<i>Induction of charge</i>	3%	5%	4%

As shown in Table 4, the original version results are similar to those of the previous subsection. Comparing the guided version to the original version, there is an increase of the correct answer and reasoning. However, it seems that some students who were not sure how the electric field changed, with the question guide, they answered the correct result. There is evidence, according to Table 4 that those students who do not understand induced charge (and electric field produced by that charge) are not helped by the guided question.

Furthermore, the extended guided version results are very similar to those in the guided version indicating that further guidance did not help students to overcome their difficulties.

SUMMARY

This report is part of a preliminary study on the understanding of electric fields. The most important findings are:

- The E-field due to charges is not well understood. Students tend to draw lines (probably field lines) instead of thinking about interactions.
- Replacing real objects with abstract objects in does not have an effect on the performance of students in electrostatic questions.
- The effect of charges on conductors is not well understood and subsequently the Superposition Principle is not well applied.
- The effect on charges on insulators is not understood at all.
- Guided questions help in some extent to help students who were otherwise unsure about their reasoning to get a correct answer and reasoning. However, the guidance is limited since there is a great number of students who did not answer the questions correctly even with the guided questions.

A current investigation is undergoing to further study the level of students' understanding of the electric field concept.

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