Levels of Students' Understandings of Electric Field Due to a Continuous Charged Distribution: A Case Study of a Uniformly Charged Insulating Rod

Thanida Sujarittham, Narumon Emarat, Jintawat Tanamatayarat, Kwan Arayathanitkul, Suchai Nopparatjamjomras

Abstract**—**Electric field is an important fundamental concept in electrostatics. In high-school, generally Thai students have already learned about definition of electric field, electric field due to a point charge, and superposition of electric fields due to multiple-point charges. Those are the prerequisite basic knowledge students holding before entrancing universities. In the first-year university level, students will be quickly revised those basic knowledge and will be then introduced to a more complicated topic—electric field due to continuous charged distributions. We initially found that our freshman students, who were from the Faculty of Science and enrolled in the introductory physic course (SCPY 158), often seriously struggled with the basic physics concepts—superposition of electric fields and inverse square law and mathematics being relevant to this topic. These also then resulted on students' understanding of advanced topics within the course such as Gauss's law, electric potential difference, and capacitance. Therefore, it is very important to determine students' understanding of electric field due to continuous charged distributions. The open-ended question about sketching net electric field vectors from a uniformly charged insulating rod was administered to 260 freshman science students as pre- and post-tests. All of their responses were analyzed and classified into five levels of understandings. To get deep understanding of each level, 30 students were interviewed toward their individual responses. The pre-test result found was that about 90% of students had incorrect understanding. Even after completing the lectures, there were only 26.5% of them could provide correct responses. Up to 50% had confusions and irrelevant ideas. The result implies that teaching methods in Thai high schools may be problematic. In addition for our benefit, these students' alternative conceptions identified could be used as a guideline for developing the instructional method currently used in the course especially for teaching electrostatics.

Keywords**—**Electrostatics Electric field due to continuous charged distributions, inverse square law, superposition principle, levels of student understandings.

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I. Introduction

UNDERSTANDING of electric field due to continuous charged distributions plays a significant role in science students' future learning both in advanced lecture courses and laboratories. Especially, in real-world situations, there are charged objects containing a large number of point charges in various shapes. To be able to understand and explain such phenomena happening is a main aim of learning physics. The understanding of electric field due to continuous charged distributions will be required from students. Therefore, survey of students' understanding of this topic is worthy. As this topic is very 'compact or dense', many students cannot success understanding and solving problems concerning about representation-rich ideas [1]-[3]. From our pilot study in 2010, a large class of first-year science students was observed and taken notes by the first author. Lecturers had taught a general integral for calculating the net electric field E. Then students were asked to solve a simple problem: finding the electric field at point P located at a distance from one end of an insulated thin rod carrying a uniform distributed charge$+Q$. Generally, students could recognize the steps for solving the problem. They performed chopping the whole rod into infinitesimal segments dq, setting up the expression for dE, and lastly integrating the infinitesimal element. However, they had significant difficulties with the process of setting up the initial equation for integrating dE [4], [5]. They did not have sufficient understanding of the physical meaning of the infinitesimal elements resulting to the magnitude of dE [6]. They could not correctly select the equivalent infinitesimal element relating to a coordinate to substitute dq in which led them to set up incorrect integral of dE. Moreover, in other complex questions involving to the change of directions of dE, many students integrated dE by neglecting the vector character of dE (in agreement with the result of [7], [8]).

The above mentioned result initially guided us to know what students encountered challenging. This then activated us need to have more clear understanding of students' conceptions. Therefore, the goal of this study is to investigate the following question: What are levels of Thai freshmen science students' understandings of electric field due to a continuous charged distribution?

II. Participants

A group of 260 Thai freshman science students was selected as samples of this study. All of them were enrolled in the introductory physics course (SCPY 158) and were taught by two lecturers in the second semester. The background knowledge of these students was quite similar. They had just graduated high school, successfully completing the Thai national science standard curriculum for high school developed by the Institute for Promotion of Science Teaching (IPST).

III. Instrument and Data-Collection Procedure

To understand the conceptions of visualizing and representing net electric field that were behind a formula that would be set up by students from translating their knowledge, the open-ended question (Fig. 1) was administered to students as a pre-test and re-administered as a post-test after 7 weeks of instruction. The question was adapted from standard textbooks and standard tests [9]-[11].

Draw the vector at points 1 and 2 to show the net electric field due to the insulated rod of length *L* that carries a uniform charge +*Q*:

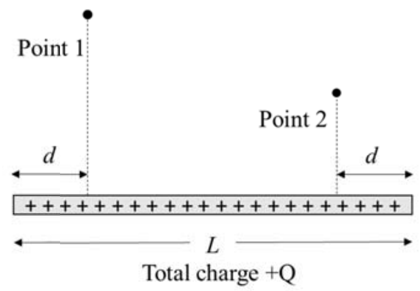

Fig. 1 The question used to probe students' understanding

To understand students' thinking, 30 students were sampled for interviews. A semi-structured interview style was conducted with individual students. Each interview was implemented within two weeks after the students had completed the post-test. The open-ended question was reused as the material for interviewing the students' individual responses. They were asked to recall their personal idea on the question via a thinking aloud technique. Each interview was implemented as a conversation until the interviewer clearly understood the students' ideas.

IV. Data Analysis

All responses were analyzed based on the following categories [12]-[15]:

- Sound understanding (SU): Responses that include all components of the scientifically accepted ideas.
- Partial understanding (PU): Responses that include at least one of the components of a validated answer, but not all the components.
- Partial Understanding with Specific Alternative Conception (PUSA): Responses that show understanding of the concept, but also make statements which demonstrate a misunderstanding.
- Specific Alternative Conceptions (SAC): Responses that include illogical or incorrect information.
- No understanding (NU): Responses that consist of repeating a part of or full question; irrelevant or unidentified response; or no response.

V. Result and Discussion

To solve this problem, students need to integrate two ideas: the superposition principle and the inverse square law of electric fields through graphical representation of vectors. The criteria for classification of student understanding levels and the result of students' responses are shown in Table I and Fig. 2 respectively.

TABLE I
STUDENT UNDERSTANDING LEVELS

Understanding level	Description	%students (*n=260*) Pre-test	Post-test
SU (Response 1)	Students used the superposition principle together with the inverse square law of infinitesimal electric fields to illustrate the net electric field vectors.	3.1	26.5
PU (Response 2)	Students used only the superposition principle without the inverse square law of infinitesimal electric fields to illustrate the net electric field vectors.	1.5	10.8
PUSA (Response 3)	Students used the superposition to illustrate the net electric field vectors. They had the alternative conception of the inverse square law.	40.8	6.9
SAC (Responses 4-8)	Students didn't use or partially used the superposition principle in order to illustrate the electric field vectors. Some of them also had alternative conceptions of the inverse square law.	15.4	30.8
NU (Responses 10 - 12)	Students showed irrelevant or unidentified responses. Some of them did not sketch any vectors.	39.2	25.0

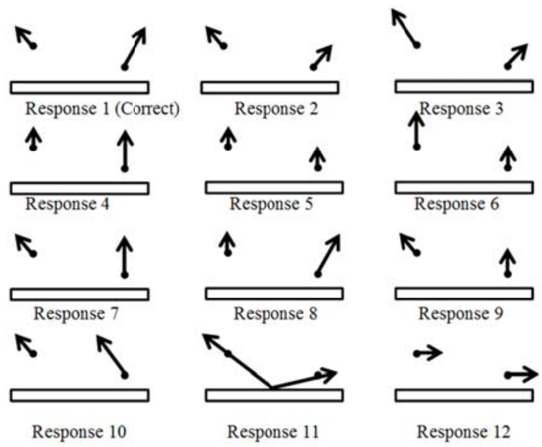

Fig. 2 The example of students' responses

The result of pre-test, shown in Table I and Fig. 2, was that, 39.2% responded with irrelevant ideas. Of 42.3%, some students showed partial understanding and many of them had partial understanding with alternative conceptions. 15.4 % had alternative non-standard conceptions, and only 3.1% showed sound understanding. There was a small shift on the post-test with 26.5% of students demonstrating sound understanding. 10.8% had partial understanding. The number of the students was greater with 30.8% in the alternative understanding level as it was lower in the partial understanding with alternative ideas level. 25% of the students demonstrated no understanding.

A. Student Reasoning for SU

After completing the lectures, 26.5% of the students had sound understanding. Some students indicated chopping the line of charge into two segments vertically below the points. One segment was longer (causing greater field), the other was shorter (causing smaller field). Hence, the direction of the net electric field vectors at points 1 and 2 would point to the up-left and the up-right directions, respectively. The net field strengths at the two points were compared relative to the inverse square law from each point.

Other students indicated chopping the line of charge into small segments of charge dq and then summing the fields from symmetrically located charge segments below on both sides of the point. The result of summing the field vectors would be upward at the point. The remaining charge segments were summed contributing either an up-left or up-right electric field. Then, it was summing the net fields due to the symmetrical and the remaining charge segments. Next, it was doing the same process for the other point. The last step was comparing the magnitude of the net electric field vector at the points via the inverse square law.

The following are quotations from the interview session as an example of this SU level.

Interviewer: Please describe me and write down what you are describing on the paper to show how you get this solution.

Interviewee: If the considered point is located symmetrically above the line of charge, the net electric field vector should point upward. Anyway, it is not this situation. From the figure, the point is not in the middle above the line. Therefore, the net electric field vectors will point to the up-left and the up-right at points 1 and 2, respectively (The interviewee sketched the vector at the two points). It seems the electric field component vectors do not cancel completely.

Interviewer: Why do you think that the electric field vectors do not cancel completely?

Interviewee: Okay, I will show you the decomposition of all vectors. Suppose that the point is in the middle (the interviewee sketched the vectors due to small charge elements, did the composition of vectors, and then represented the net electric field vector). The electric field component vectors can cancel completely.

Interviewer: Yep, I got that.

Interviewee: And in this question, it seems like I chop the line of charge like this. Suppose that we are to find the electric field vector at point 1 (The interviewee pointed at point 1 and then moved her hand to cover the non-symmetrical segments). The net electric field vector should point upward if there are only the electric fields from symmetrical segments. Anyway, if we include these segments covered (The interviewee move her hand to expose the remaining segments), it causes the horizontal components of electric field vectors. The net vector should then point to this way (The interviewee points to the up-left).

Interviewer: What about the other point?

Interviewee: I did the same. I initiated to find the net electric field vector from the symmetrical segments. That causes the vector pointing upward.

Interviewer: And for the remaining segments?

Interviewee: Yep, all of them were summed up together. That results the net electric field vector pointing in the up-right direction.

Interviewer: And can you compare the magnitude of the net electric field vectors?

Interviewee: In comparison (The interviewee pointed at the vector sketched at point 2), this should be longer because the point is closer to the line of charge.

B. Student Reasoning for PU

Students indicated chopping the line of charge into two segments vertically below the points. One segment was longer (causing greater field), the other was shorter (causing smaller field). Hence, the direction of the net electric field vectors at points 1 and 2 would point to the up-left and the up-right directions, respectively. However, the comparison of the net field strengths at two points was ignored. Most of them did not think of the inverse square law.

The following are quotations from the interview session as an example of this PU level.

Interviewer: Please describe me and write down what you are describing on the paper to show how you get this solution.

Interviewee: As I think, I chop the line of charge into two segments vertically below the points. Look at this point! (The interviewee pointed at point 1 and then moved his hand to cover the segment located in the right side of point 1). If we sketch vectors due to equally small segments of this side, they should have fewer numbers than the right side, shouldn't they? Therefore, the net electric field vector should go to the up-left. Anyway, I just sketched its trend.

Interviewer: And can you compare the magnitude of the net electric field vectors?

Interviewee: I can't tell. It might need integration.

C. Student Reasoning for PUSA

Students indicated chopping the line of charge into two segments vertically below the points. One segment was longer (causing greater field), the other was shorter (causing smaller field). Hence, direction of the net electric field vectors at points 1 and 2 would point to the up-left and the up-right direction, respectively. However, the comparison of the net field strengths at two points was directly proportional to the distance.

The following are quotations from the interview session as an example of this PUSA level.

Interviewer: Please describe me and write down what you are describing on the paper to show how you get this solution. How do you get these directions of vectors?

Interviewee: I might remember some ideas from the mid-term exam. At point 2 (The interviewee pointed at point 2), the point is on the right hand side. That means the segment, whose the greater amount of charge is on the left hand side below the point, will generate the greater electric fields to the up-right. The net electric field vector should go to the up-right as well.

Interviewer: Do you represent the electric field strengths by vectors?

Interviewee: I sketched the longer vector at point 1.

Interviewer: Why did you do it like that?

Interviewee: That is because the point is far from the line. For point 2, it is in the shorter distance. It will generate electric fields at the shorter distance.

Interviewer: So, at the shorter distance, the charge will generate the smaller electric field strengths.

Interviewee: Yes.

D.Student Reasoning for SAC

In the main alternative conception, students sketched the vector pointing straight upward at both points. For example, they thought only the nearest infinitesimal segment generated the net electric field at the points [6] even though they had chopped the line of charge into small segments and recognized the superposition principle. Some sketched the net field vector at each point by summing only the segments of dE that were located symmetrically. Some students could not discriminate between the electric field due to an individual segment of charge and the net electric field at a point due to a line of charge. Thus, they chose only a small segment of charge below the point to represent the net electric field. These reasonings relate to responses 4-6 (Fig. 2).

Responses 7-9 (Fig. 2) contained students' difficulty with the superposition principle. They correctly sketched the net electric field vector for the point on the left or on the right with correct reasoning. For the point on the right, which is close to the line of charge, they believed the field would be like that of an infinite line of charge, consequently pointing straight up. For the point on the left, which is far to the line of charge, they believed that the field would be from the nearest infinitesimal segment only. For comparing the magnitudes at two points, some students thought of the inverse square law but some did not.

The following are quotations from the interview session as an example of this SAC level (See response 4 in Fig. 2).

Interviewer: Please describe me and write down what you are describing on the paper to show how you get this solution. How do you get these directions of vectors?

Interviewee: As I recognized, I will explain vectors going straight upward. It is contributed from the electric field from only the nearest small segment locating vertically below the point. The other segments contribute rather weak electric fields at the point (The interviewee pointed the segments being away from the point). When summing up electric field vectors carefully, the net vector should go upward.

Interviewer: As you have described, it informs that you simply find and then sketch the net electric field vector according to the fields of the nearest segments to the point, don't you?

Interviewee: I do sum all vectors at the point. Among the others, the electric field from the nearest segment will have most effect on the net electric field vector at the point. That causes me to sketch the net electric field vector pointing straight upward.

Interviewer: And what about comparing the electric field strengths at the two points?

Interviewee: At that time, I used the formula; $E = {}^{kq}/_{R^2}$. If the point is at a longer distance, the electric field will be smaller.

Interviewer: Okay.

E. Student Reasoning for NU

The main difficulty of this student group was from finding the net field vector and the superposition principle. Most students could recognize that the total electric field was the vector sum of the infinitesimal fields, but they could not apply this physics in this contextual problem.

The following are quotations from the interview session as an example of this NU level (See response 11 in Fig. 2).

Interviewer: Please describe me and write down what you are describing on the paper to show how you get this solution. How do you get these directions of vectors?

Interviewee: It is the positive charge. Electric fields should point outward.

Interviewer: Did you intend to sketch the vectors at the two points by passing through the middle of the line?

Interviewee: Yes, I did.

Interviewer: Why did you do that?

Interviewee: Because it is a center point, Hmmm, it is like the teacher taught that we should begin to sketch from the middle of the line. Hmm, I recognized this (The interviewee sketched the equal vectors pointing upward in a radius around the middle small segment). So, the net electric field vector might point up as I sketched. Anyway, I'm sure that they should point outward.

Interviewer: About the magnitudes, did you compare those between the points? Do you have any ideas?

Interviewee: I thought of the distance.

Interviewer: Please explain.

Interviewee: This point is far (The interviewee pointed at point 1). To exert force to the point, the force should be stronger than the closer point (point 2).

Interviewer: If the considered point is at a longer distance, the force contributing to that point should be stronger. That's your idea, isn't it?

Interviewee: Hmm………Oh! yes, it is.

From the result, we note that students had different understandings of the concepts of superposition principle and the inverse square law of electric fields. Most students had misconception or no understanding, which did not give satisfactory reasons to the open-ended question even they had just learned from the class.

V. Conclusion and Implication

For this study, it was to investigate and classify students' conceptions of electric field due to the simple continuous charged distribution. Most students did not give satisfying responses on the open-ended question. It was because they ignored the core conception that all infinitesimal segments of charge definitely affecting the change of the direction and the magnitude of the net electric field. Interestingly, the basic concept—the inverse square law was also difficult for students even they had learned from high school.

This indicates that students' understanding still needs to be improved. Some active learning method should be considered and integrated to the class for supporting student learning.

Acknowledgment

We would like to thank the Faculty of Science, Mahidol University for funding to do this research project. Additionally, we would also like to extend our sincere thanks to the Institute for Innovative Learning and the Department of Physics at the Faculty of Science, Mahidol University for their kind support.

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