Students’ understanding of the inverse square law in electrostatics

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Abstract. One problem of learning Electrostatics is that students often learn from their common-sense beliefs about electric force and electric field. This study investigated students’ conceptual understanding of finding electric force, electric field, and electric potential of point charge after learning an introductory physics course. We administered the Electrostatics Conceptual Evaluation Test to four lecture-based classes in high school. The first question was a comparison of the electric force from two-point charges at two different positions and the second question was a comparison of the electric field from a point charge at two different positions. The use of the inverse square law is required to find the electric force and the electric field at various positions. It was found that many students answered incorrectly. They described that the electric force and the electric field decrease whereas the distance increases by neglecting the inverse square law. This finding can be particularly used to suggest high school teachers to develop their effective strategy to support student learning.

1. Introduction

Many reports have been found that many students have misunderstanding in Electrostatics, especially in the concept of the inverse square law of electric field [1-3]. This misunderstanding causes student learning difficulties in the topics of electric force, electric field, and electric potential in introductory physics course. Our preliminary study is an investigation of 162 first-year university students’ conceptual understanding about finding the electric field due to a point charge by using the Electrostatics Conceptual Evaluation Test as pre- and post-tests. There were two questions of interest. The first question was about determining the electric field due to a point charge at two different positions with one being twice the distance of the other. The use of the inverse square law was required to solve the problem. It was found that 69.8% and 25.9% of the students could not give the correct answer in the pre- and post-tests respectively. The second question was about determining the electric field due to a point charge enclosed by the different Gaussian surfaces. It was found that 77.8% and 31.5% of the students were not able to find the correct solution in the pre- and post-tests respectively. From this finding, most of students expressed electric field by neglecting the inverse square law. This initial study encouraged us to pursue students’ understanding of the inverse square law in high school in order to be a guidance for teachers to develop their own teaching strategy.

2. Methodology

2.1. Samples

125 high school students from four lecture-based classes who enrolled in the Physics course in 2020 were the samples of this study.

2.2. Measurement and data collection

In this study, we administered the Thai version of the Electrostatics Conceptual Evaluation Test to the students after they learned Electrostatics. The test was developed from a standardized test and physics textbooks [4, 5]. There were three questions of interest and the students were required to use the inverse square law to solve the problems. The first question was a comparison of the electric force due to point charges at two different positions. The second question was a comparison of the electric field due to a point charge at two different positions. Subsequently, the last one was a comparison of the electric potential from a point charge at two different positions.

3. The questions

Question 1: The electric force between the point charges + Q and +2Q has a magnitude of F as shown in figure 1. If the charge + 2Q is shifted to positions A and B. What is the magnitude of the electric force acting between the two point charges for each position?

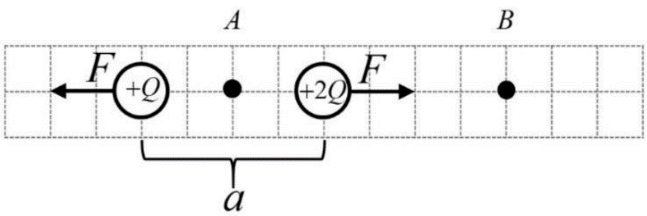

Figure 1. Positions A and B from the two point charges.

Question 2: The particle with the charge + Q is fixed. The electric field from this particle at position P has a magnitude of E_0 and its direction as shown in figure 2. What is the magnitude of the electric field at positions A and B?

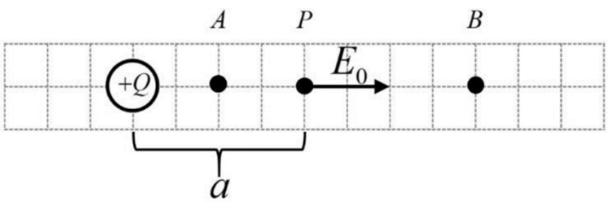

Figure 2. Positions A and B from the point charge +Q.

Question 3: The particle with the charge + Q is fixed. The electric potential from this particle at position P is V_0 as shown in figure 3. What is the electric potential at positions A and B?

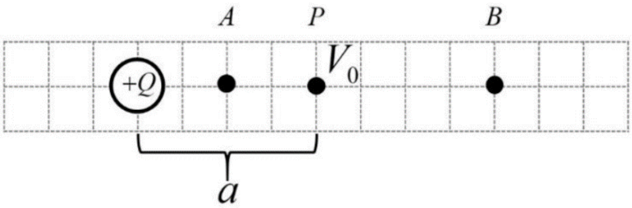

Figure 3. Positions A and B from the point charge +Q.

4. Results and discussion

From testing, only 8% provided the correct answers. This result confirmed that most students had misunderstandings in finding the magnitude of the electric force between the two-point charges and the electric field due to the point charge (see table 1).

It was found that most students answered incorrectly. They described that the electric force and the electric field decrease whereas the distance increases by neglecting the inverse square law (See figure 4). Only 7-9% of students were able to link the inverse square law to determine the electric force and the electric field.

In addition, the result shows that students continuously used the similar alternative ideas to solve the third problem—finding the electric potential at two different positions. Interestingly, 90% of them who could find the electric potential correctly were from the same group of the students determining the magnitude of electric force by neglecting the inverse square of the distance (See figures 4, 5, 6, and 7).

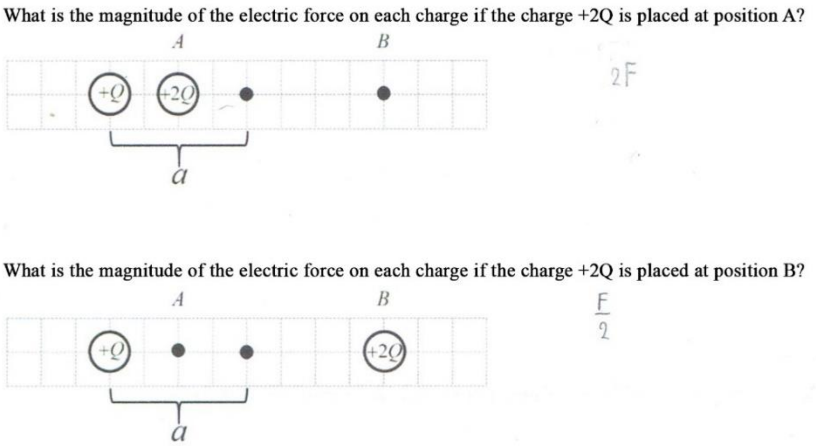

Figure 4. The example of student’s answers who determined the electric force being inversely proportional to the distance in question 1.

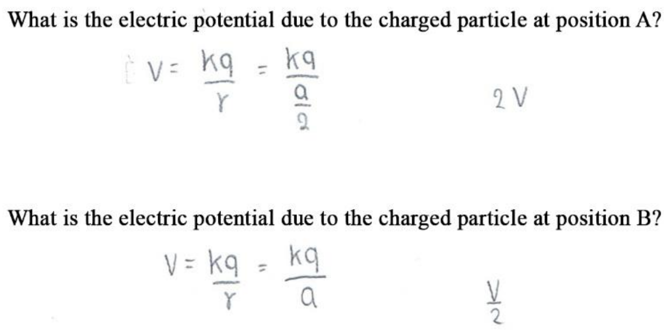

Figure 5. The example of student's answers who determined the electric potential being inversely proportional to the distance in question 3.

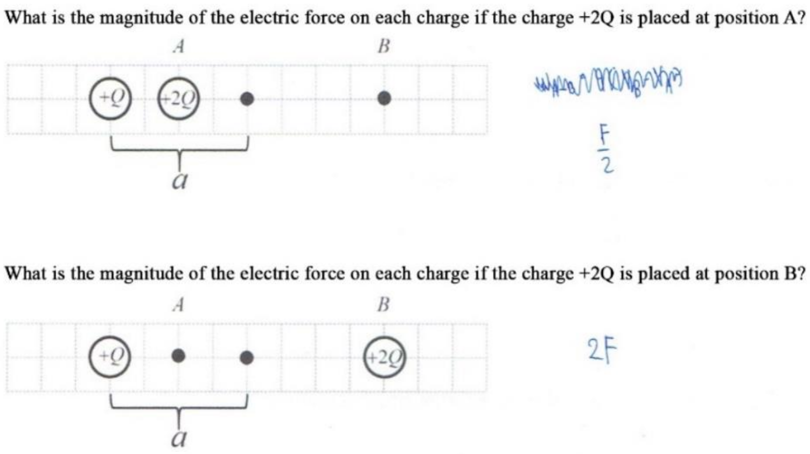

Figure 6. The example of student's answers who determined the electric force being directly proportional to the distance in question 1.

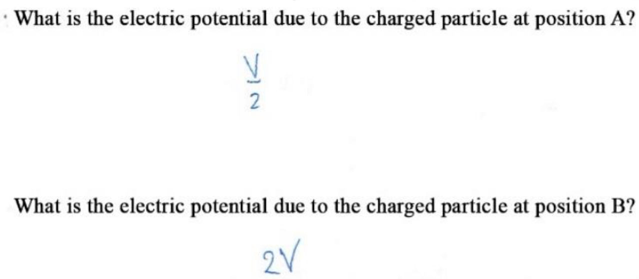

Figure 7. The example of student's answers who determined the electric potential being inversely proportional to the distance in question 3.

Table 1. The students' answers to the test for questions 1 and 2.

	Percentage of students
When the distance increases, the magnitude of the electric force decreases at the same rate. (figure 4)	67%
When the distance increases, the magnitude of the electric force increases at the same rate. (figure 6)	17%
The magnitude of the electric force is inversely proportional to the square of the distance between the point charges.	9%
When the distance increases, the magnitude of the electric field decreases at the same rate.	65%
When the distance increases, the magnitude of the electric field increases at the same rate.	10%
The magnitude of the electric field is inversely proportional to the square of the distance from the point charge.	7%

5. Conclusions

After completing the lesson, most students employed their common-sense beliefs to solve the electric force and electric field problems. They described that electric force and electric field by neglecting the inverse square law. According to the investigation deploying the three basic questions, it particularly suggests that high school teachers need to develop an effective teaching strategy to support their student learning in Electrostatics. In addition, this result clearly implies that physics teachers are required to devote their time for solidifying students' conceptual understanding together algebraic problem solving in the inverse square law as it relates not only Coulomb's law but also Newton's law of gravitation and the definition of intensity.

Acknowledgments

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