



Examining Knowledge Levels of High School Students Related to Conductors at Electrostatic Equilibrium and Electric Field Lines Using the Drawing Method

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Abstract

The purpose of this study was to investigate knowledge of high school students related to conductors at electrostatic equilibrium and electric field lines. The descriptive model was preferred in line with the purpose of the study. The sample of the study consisted of 35 11th grade students, 18 females and 16 males, who were enrolled in a state-owned high school in Turkey. The participants had previously learned the electric field lines in their courses. The research data was collected using a drawing scale consisting of three sections prepared by the researchers. The students then were asked to explain their drawings. Descriptive analysis was applied to the answers of the students. According to the findings obtained from the analysis, the most commonly reflected property of electric field lines was “electric field lines do not intersect,” while the least commonly reflected property was “electric field lines are drawn parallel to the surface.” Also, the students were observed to confuse the concept of the electric field with electric current, and electric field lines with magnetic field lines. In addition, it was found that the students did not understand the direction of the electric field and the vectorial nature of the electric field, and believed that electric field lines were real. The knowledge of the students was not based on scientific foundations.

Keywords Electric field lines · High school students

Introduction

In traditional teaching, the problem-solving skill is accepted to be indispensable for the physics course. However, students need to understand certain concepts correctly before they gain

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problem-solving skills (Hestenes and Wells 1992). Since the physics course usually involves abstract concepts, concretization is a commonly used method to teach abstract concepts. Models are among the most effective tools in this sense.

Scientific models are structured units of information used to represent physical phenomena with observable examples (Hestenes 1996). In other words, models are representations organized to provide a mechanism, causality, or function to explain, illustrate, and predict phenomena (Osbeck and Nersessian 2006; Schwarz et al. 2009). The electric field lines model, which was developed by Faraday, is used to teach the electric field. In his lectures, Feynman explains electric field lines as follows: “We can attempt to get a mental picture of the field by drawing vectors at many points in space, each of which gives the field strength and direction at that point. We can go further, however, and draw lines which are everywhere tangent to the vectors—which, so to speak, follow the arrows and keep track of the direction of the field” (Feynman et al. 2016).

The concept of the electric field is essential to teach electricity and magnetism. The foundation to teach other subjects is built upon the concept of the electric field. Hence, it is important that students understand the electric field correctly. Studies on this topic usually focus on misconceptions related to the concept of the electric field (Bilal and Erol 2009; Duit 1993; Furió et al. 1998; Planinic 2006; Pocovi 2007; Povoci and Finley 2002; Törnkvist et al. 1993; Saarelainen et al. 2007; Viennot and Raison 1992). The findings obtained by Povoci and Finley (2002) showed that students perceived electric field lines as real entities. Another interesting result was students’ misconceptions related to the presence of electric field lines within insulating objects. It was found that students believed the electric field to be zero in insulators since charges could not move within the insulator (Viennot and Raison 1992). Based on research findings in the literature, difficulties experienced by students when learning the electric field were organized into five categories by Bradamente et al. (2007): Definition, source/existence, representation, superposition, and motion of electric charges in the electric field.

The students were observed to perceive the electric field as tangible, which was one of the difficulties related to the definition of the electric field. Students were also found to believe that the electric field had volume, force, or density (Bohigas and Periago 2010; Bradamente et al. 2007; Furió and Guisasola 1998; Martín and Solbes 2001; Saarelainen et al. 2009). It was determined that students were not able to distinguish between the electric field and the electric force in their explanations related to electrostatics. It was observed that students had a tendency to use the concept of electric force instead of the electric field when answering questions related to the motion of the charged particle in the electric field (Bilal and Erol 2009; Furió and Guisasola 1998; Martín and Solbes 2001). Similarly, it was found that high school students failed to use the electric field when explaining the charging of a condenser (Eylon and Ganiel 1990); students failed to use the electric field when explaining the electromagnetic induction (Thong and Gunstone 2008).

The concept of charge is important to understand the concept of the electric field. In terms of difficulties related to the source of the electric field, students were observed to associate the presence of electric field at a given point with the presence of electric charge at said point. They were found to believe that there would be no electric field in the absence of electric charge (Bohigas and Periago 2010; Furió and Guisasola 1998; Velazco and Salinas 2001). It was determined that students only partially understood the charge distribution along conductors, and had almost no understanding of the charge distribution along insulators (Garza and Zabala 2010).

Another category determined in relation to the subject was the representation of the electric field. In this category, students were observed to draw the direction of electric field lines outward from the object without considering the charge (Garza and Zabala 2010). Moreover, students believed that the charge would be subject to a force at section where electric field lines were drawn, and that there was no electric field in gaps between electric field lines (Bilal and Erol 2009; Povoci and Finley 2002).

In terms of difficulties related to the superposition of the electric field, it was seen that students failed to understand the vectorial nature of the electric field. This was suggested as one of the most significant reasons behind difficulties experienced in relation to electrostatic subjects in numerous studies (Bradamente et al. 2007; Nguyen and Meltzer 2003; Saarelainen et al. 2007; Povoci and Finley 2002, 2003, 2007). As a result, students tend to believe that the electric field would not change when a new positive charge is added to the system (Sandoval and Mora 2009; Viennot and Raison 1999); however, the field would decrease when a negative charge is added (Sandoval and Mora 2009).

Research findings related to difficulties experienced by students in relation to the motion of a charged object in the electric field showed that students believed the path of a charge moving freely in the electric field to be in the same direction with field lines passing through the charge (Pocovi and Finney 2002; Törnkvist et al. 1993). Students were found to believe that charged particles in a uniform electric field would move at a constant velocity (Bilal and Erol 2009; Sandoval and Mora 2009), while charged particles moving in the opposite direction of the electric field would move more slowly (Bilal and Erol 2009).

Another problem is students confusing the electric field with other concepts. There are various studies conducted using the Conceptual Survey of Electricity and Magnetism (Maloney et al. 2001), which was developed to measure knowledge levels of university students related to electricity and magnetism. Common findings obtained in these studies indicate that students confuse the electric field with magnetism, and incorrectly interpret electric field lines (Maloney et al. 2001; Planicic 2006; Saarelainen et al. 2007). Similarly, one study performed with science (physics and chemistry) teachers revealed that they confused the electric field and the magnetic field (Hekkenberg et al. 2015).

Studies focusing on reasons behind learning difficulties experienced by students in relation to the electric field point to the difficulty of understanding this abstract concept. Another reason was found to be insufficient knowledge about mathematics and basic physical concepts (Dunn and Barbanel 2000; Furió and Guisasola 1998). It was suggested that the teacher must ensure that students acquire a good understanding of Newton's laws and are able to make necessary association to teach Coulomb's law (Furió and Guisasola 1998). Instead of holding students responsible for difficulties experienced in relation to this subject, there are also studies suggesting that such difficulties arise from the use of a poor teaching method (Furió et al. 2003). Some studies suggest that textbooks and curricula which ignore different formulations emerging during the development of the theory instead and do not employ an accumulative linear approach are responsible for such difficulties (Guisasola 1997; Stocklmayer and Treagust 1994; Strube 1988).

Understanding the electric field is important to learn electricity and magnetism. If students do not have a good understanding of the electric field concept, they seem to have difficulties in other subjects as well. In one study with teachers, it was found that teaching the electric field using electric field lines created a mental picture for students about what the electric field looks like. Students were observed to find it easier to make connections between rules that they had learned in Newtonian mechanics and particles when the field concept was introduced with

field lines (Melo-Niño et al. 2017). For this reason, there is a need for studies which investigate how students perceive electric field lines, which play an important role when teaching the electric field.

In line with this need, the purpose of this study was to investigate knowledge of high school students related to conductors at electrostatic equilibrium and electric field lines. Studies in the literature usually focus on knowledge of students related to the electric field concept. The properties of the electric field lines were either very little or not included in the scale used in these studies. Specifically, there are a limited number of studies on how students understand the properties of electric field lines. Among them, Törnkvist et al. (1993) focused on how students understand the electric field lines between the charged conductors. Kesonen et al. (2011) investigated the way of understanding of electric field lines between moving charged particles and condenser plates. In addition, the characteristics of the electric field lines were included in the studies investigating the force acting on the charged particle in the electric field (Povoci and Finley 2002; Saarelainen et al. 2007). There is no study investigating how students understand the electric field lines of conductive objects in electrostatic equilibrium. It is thought that understanding the properties of electric field lines will provide a basis for the advanced stages of electric field subject and subsequent electricity and magnetism subjects; this study will contribute to the literature.

Multiple-choice questions may fall short in terms of explaining the logical problem and the source of and the conceptual problem. While written open-ended questions are more effective, they are difficult to assess quantitatively and sometimes subjective (Ozay and Oztas 2003). The drawing method allows for revealing students' implicit knowledge and beliefs independent of words (Ayas 2006). This method prevents students who do not enjoy answering written questions and expressing themselves verbally from feeling limited (Rennie and Jarvis 1995; White and Gunstone 1992). Drawings of students open a window to their ideas and emotions, and present a picture of their minds (Thomas and Silk 1990).

There are studies where the drawing method was employed to determine knowledge levels, misconceptions, and conceptual changes of students related to a given subject (Kose 2008; Prokop and Fancovicová 2006; Rennie and Jarvis 1995; Reiss and Tunnicliffe 2001; Reiss et al. 2002; Sahin et al. 2008; Uzunkavak 2009; White and Gunstone 1992). Further, Acar and Tarhan (2008) demonstrated that it was possible to reveal knowledge-use skills of students more clearly using the drawing method compared to other measurement tools. For this reason, the drawing method was selected for the present study.

Method

The descriptive model, which is used to reveal an existing situation or situations as is (Creswell 2013; Sonmez and Alacapinar 2011), was selected as the research method to investigate knowledge of the students related to conductors at electrostatic equilibrium and electric field lines.

Sample

Prior to the selection of the participants, the matter was discussed with the teachers in the high school where the study was to be conducted, and only classes of those who had taught the properties of conductors at electrostatic equilibrium and electric field lines were selected.

Then, the students who confirmed that they had learned the subject and stated that they remembered the subject were included in the sample. The sample of the study consisted of 35 11th grade students, 18 females and 16 males, who were enrolled in a state-owned high school in Turkey. The participants had previously learned the electric field lines in their courses.

Education Progress

The education programs in Turkey are prepared by the Ministry of Education. Even if teachers use different sources, this program is implemented in each school regardless of schools and teachers. In the program, it is clearly stated how much time is allocated to each subject in each class, the learning outcomes of each subject, and the activities expected from students. In this study, the students studying in the classes of two different teachers were included. These students used the same textbook, studied the same examples, and did the same activities according to the physics curriculum.

Electric field lines are taught in two stages in the 9th and 11th grades of high school education. In the 9th grade outcomes, electric field subject is only mentioned conceptually, but mathematical expressions are not included. Eight course hours are allocated to electric field subject in the 9th grade. The characteristics of electric field lines are listed as items in the textbooks. Drawing samples are given for point charges; the drawings of charged objects are expected from teachers. The teachers of the students participating in this study showed the electric field lines for regular-shaped objects such as rectangular, prismatic objects and irregular-shaped objects. In the data collection in this study, no additional studies have been conducted with the students to draw the electric field lines on the desired shapes.

In the 10th grade, electrical current, electrical energy, electrical circuits, and magnetic fields are included in the physics curriculum. A total of 18 h is allocated for both electricity and magnetism subjects. In the 11th grade, electricity and magnetism subjects are further studied in 68 course hours. At this level, the subject of the electric field, which is firstly studied in the 9th grade, is briefly reminded. Mathematical calculations of point charges are included. Then, electric field lines are included in the subject of capacitors. Electric field lines subject is concentrated on the electric field between the plates of the capacitors. After this subject, magnetic flux, induction current, and alternating current subjects are taught.

The students in the study group were studying in the 11th grade. The study was conducted in the spring semester. During this time, the students studied all of the electricity subjects in the physics curriculum in their lessons. In magnetic field subjects, they completed the subject of magnetic field. They were expected to have the knowledge in the data collection tool used in the study.

Data Collection Tool

A scale consisting of three sections prepared by the researchers was used for data collection. The tasks are presented in the [Appendix](#). First of all, the researchers determined the shapes which would be asked from the students to draw in relation to electric field lines. Opinions from two experts specializing in physics teaching were received for the appropriateness of the shapes. Initially, the scale asks students for their demographic information. The 1st section of the scale includes an open-ended question, “Please write the properties of charged conductors at electrostatic equilibrium.”, and asks students to write down what they know related to the subject.

The 2nd section of the scale gives four different objects at electrostatic equilibrium and asks students to draw electric field lines for these objects. The objects include a positively charged hollow conducting sphere (2A), a positively charged solid conducting sphere (2B), a negatively charged hollow conducting sphere (2C), and a positively charged hollow conducting teardrop-shaped (due to parts with different radius of curvature) object (2D).

In the 3rd section of the scale, students are given drawings of electric field lines for two different objects at electrostatic equilibrium including various mistakes. Firstly, the scale asks students to determine whether or not the drawings contain mistakes and mark the relevant option accordingly, and if they decide that the drawings contain mistakes, to state the reason why. The objects include a negatively charged hollow conducting semi-sphere (3A), and a positively charged conducting heart-shaped (due to parts with different radii of curvature) object (3B).

Data Analysis

The data was evaluated using the descriptive analysis method. Each item in the drawing scale was evaluated separately for the investigated property. When a drawing was found to reflect the desired property, it was given 1 point. At this stage, two experts scored the drawings separately, and then discussed on disagreements. After the scoring was given its final shape, the total score was determined for each property, and this total score was divided by the highest possible score to calculate the success rate for each property. Information related to these properties, which are the main subjects of the study, and the relevant scale section can be found in Table 1.

As an example for how the scoring was performed, Table 2 shows scores given to S1 for his drawing (Fig. 1) for the item 2A.

S1 obtained 1 point for property 1 because he did not draw electric field lines within the sphere; 0 points for property 2 because he did not draw the lines perpendicular to the surface; 1 point for property 3 because he drew the positive charge from the object and correctly stated its direction; and 1 point for property 5 because his lines did not intersect.

As the second stage of data collection, the interviews were conducted with the students whose drawings were not understood for each phase. These students were given the opportunity to explain their drawings. In the first stage of the data collection tool, it was found that the properties of electric field lines written by the students who made the

Table 1 The distribution of the properties of conductors at electrostatic equilibrium and electric field lines by scale item

Property no.	Property	Scale section including the property	Highest possible score
1	The electric field within the conductor is zero.	1, 2A, 2B, 2C, 2D, 3A	6
2	Electric field lines are perpendicular to the surface.	1, 2A, 2B, 2C, 2D, 3A, 3B	7
3	Electric field lines are drawn from (+) charge to (−) charge.	1, 2A, 2B, 2C, 2D, 3A	6
4	Electric field lines are denser at pointed ends of a conductor.	1, 2D, 3A, 3B	4
5	Electric field lines do not intersect.	1, 2A, 2B, 2C, 2D, 3B	6

Table 2 Sample scoring

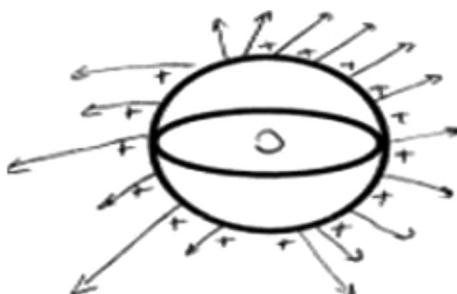
P. no.	Property	Score
1	The electric field within the conductor is zero.	1
2	Electric field lines are perpendicular to the surface.	0
3	Electric field lines are drawn from (+) charge to (–) charge.	1
5	Electric field lines do not intersect.	1

expected drawings were compatible with their drawings. Therefore, no interviews were conducted with these students. The interviews included 13 students who made drawings with the literature. The interviews were conducted by each student's own teacher in the meeting room in the school. The duration of the interviews varied between 17 and 25 min. The teachers asked the students to explain their drawings. The teachers firstly tried to understand the drawings without interfering with the students. In the interviews, the scale items in which students made interesting drawings were focused on. The questions about the characteristics of the electric field lines, the vector representation, and the electric field concept were developed according to these items. The detailed questions developed based on the students' answers were developed to form a framework for the classification of their answers. The notes taken by the teachers during the interviews were read again to the students and their approvals were obtained. Subsequently, the interview notes were subjected to descriptive analysis and presented in the findings.

Validity–Reliability

In qualitative studies, concepts of credibility, transferability, consistency, and confirmability are used instead of validity and reliability (Guba and Lincoln 1989; Koch 2006; Miles and Huberman 1994; Yildirim and Simsek 2005; Yilmaz 2013). In order to ensure credibility, each property of electric field lines was researched through multiple items of the scale. The students were asked questions about their drawings in order to avoid misinterpretations and ensure confirmability. Data triangulation was employed in the study; findings obtained from the scale were supported by questions asked to the students. The student selection was performed according to certain criteria and processes were described in as much detail as possible to ensure transferability. The study data was coded separately by two experts, and the agreement level between the experts was checked for consistency. The following formula was used to this end: “Reliability = [Agreement / (Agreement + Disagreement)]” (Miles and Huberman 1994). At the end of this process, 100% agreement was achieved.

Fig. 1 The drawing of student coded S1



Findings

The drawings and answers of the students were assessed based on five properties of conductors at electrostatic equilibrium and electric field lines as shown in Table 1. The data obtained from the scale and drawings of the students were organized as numerical distributions for all students. Qualitative findings related to the properties examined in the study were interpreted based on the drawings of the student and quotes from their answers.

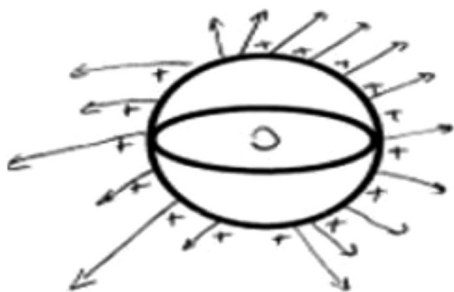
The Findings Related to Property 1: “The electric field within the conductor is zero”

This property was examined in all three sections of the scale through six items in total. Figure 2 shows the distribution of student scores for this property by scale item.

As shown in Fig. 2, 9 students (26%) stated that the electric field within the conductor was zero when asked about the properties of conductors at electrostatic equilibrium in item 1. The drawings of the students for different objects (2A, 2B, 2C, 2D) in item 2 showed that the students mentioned this property mostly ($f=19$; 54%) for the positively charged hollow conducting sphere (2A). The item with the lowest number of correct answers for this property was 3A ($f=7$; 20%). The total score for property 1 was 77, while the success rate was 37%.

As shown in Fig. 2, the correct answer percentage was different for 2A and 2B. However, we would expect the same drawings for both items, while the correct answer percentage for 2A was higher compared to that of 2B. In other words, some students who correctly answered 2A

A. A positively charged hollow conducting sphere



B. A positively charged solid conducting sphere



Fig. 2 The distribution of student scores for property 1 (The electric field within the conductor is zero) by scale item

failed to answer 2B correctly. For example, Fig. 3 shows the drawing made by S1. The explanation of the student for his drawing was as follows:

The sphere is already hollow in A. The electric field would be zero within the field; I wrote that already. We draw that normally. The sphere is solid in B. But the electric field is zero within the sphere, it accumulates on the surface. The object is round; therefore, the surface is round as well. The electric field is like this.

According to the explanation of S1, although he stated that the electric field was zero within both of the spheres, he attributed this property to the hollow structure of 2A. The student was observed to believe that electric field lines depended on the object's shape for solid objects. Although the student produced a drawing that was very close to correct for 2A, his explanation was not based on scientific facts.

Another interesting drawing made by the students can be seen in Fig. 4. This drawing was common for 3 different students; hence, it was believed that they might have copied it from each other. However, it was not possible when the seating arrangement is taken into account. The students made this drawing only for hollow spheres given in 2A and 2C'. They did not produce the same drawing for the solid sphere in 2B. When asked about the reasoning behind the drawing, S14 made the following explanation:

The electric field is zero within the sphere, that is why I did not draw it. I drew charges on the surface lines, because charge would be on the surface. In a three-dimensional sphere, they would be drawn on the entire surface. I could not draw the other sphere. I could not figure out how to draw it, because it is solid.

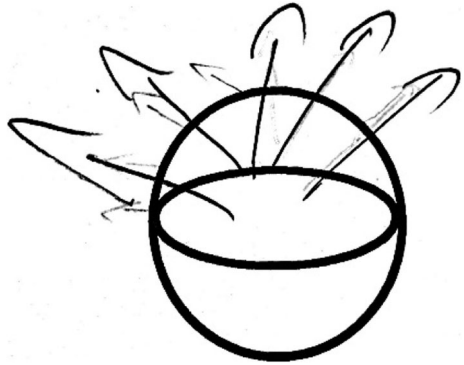
The fact that S14 stated electric field to be zero within the hollow sphere, yet did not know what to do for the solid sphere, indicates that he did not have a scientific explanation for property 1. Also, it is possible to say that his knowledge related to electric field lines was insufficient.

S32 made the same drawing shown in Fig. 5 for 2A, 2B, and 2C. When asked about why he drew lines only on the upper portion of the sphere, the student made the following explanation:

Fig. 3 The drawing of student coded S1



Fig. 4 The drawing of students coded S13, S14, and S15



As far as I know, the lines cluster above the object. Do they exist below the object as well? There should not be lines below the object. Because then the lines would have to pass through the object when moving from downward to upward. But the electric field must be zero within the object.

S32 was observed to know that the electric field was zero within the sphere; however, his knowledge was not really based on scientific facts.

Seven of the students did not make any drawings for the solid sphere in 2B, and drew electric field lines passing through the charged particles for other items. For example, Fig. 6 shows the drawing made by S2 for 2D. The student explained the drawing as follows:

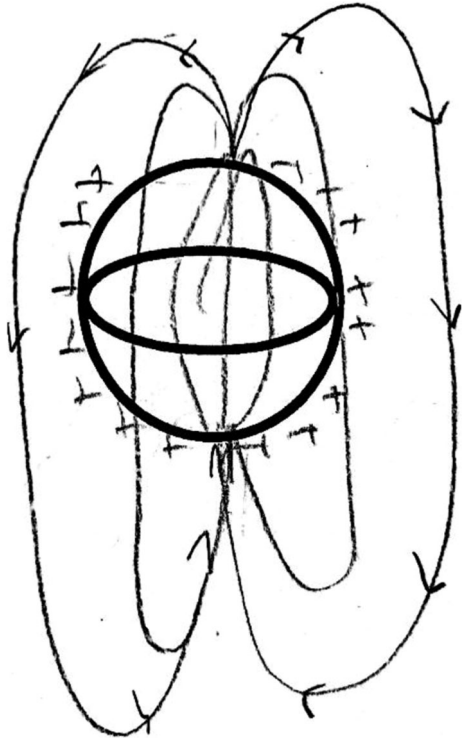
These objects are conductors. Since they are conductors, there must be electricity in every part. Like a cable, for instance. Is it possible for the cable to have electricity at certain parts and no electricity at others? I had to draw lines because electricity would spread to every part of the object.

It was concluded that the students had no knowledge about the electric field being zero within the conductor. Also, S2 was observed to confuse the electric field concept and the electric current concept.

Fig. 5 The drawing of student coded S32



Fig. 6 The drawing of student coded S2



The Findings Related to Property 2: “Electric field lines are perpendicular to the surface”

This property was examined through seven items in total. Figure 7 shows the distribution of student scores for this property by scale item.

As shown in Fig. 7, when asked about the properties of conductors at electrostatic equilibrium (item 1), only 2 students (6%) mentioned that electric field lines were supposed to be drawn perpendicular to the surface. In their drawings, the students showed the highest success rate in 2A ($f=11$; 32%), and the lowest success rate in 2D ($f=1$; 3%). For the drawings with mistakes, 11 students (31%) stated that “Electric field lines should have been drawn perpendicular to the surface” in relation to 3A. For 3b, none of the students mentioned that electric field lines should have been drawn perpendicular to the surface. The total score for property 2 was 37 for the entire scale, whereas the success rate was 15%.

In the interviews, one of the students stated that electric field lines should have been drawn perpendicular to the surface, yet he could not reflect this in his drawing. Other students, on the other hand, did not mention electric field lines being drawn perpendicular to the surface. They gave the following answers when asked, “Can electric field lines be drawn perpendicular?”:

S1 (drawing in Fig. 1): I do not know, I would not draw them perpendicular to the surface. If they need to be perpendicular, I do not know why. Does electricity travel perpendicularly? I cannot make sense of it.

S2 (drawing in Fig. 5): I do not think it is necessary to draw them perpendicular to the surface; they pass both perpendicular and parallel. The field line has the power to pierce

through the object. It would pass in any case. Because it is powerful. And the object is a conductor. It conducts electricity, so lines would pass.

S32 (drawing in Fig. 4): How would the lines know to pass perpendicular to the surface. I think it would be random. What is important is they do pass without bending. Because lines do not bend. They carry electricity.

These explanations indicate the students did not know about electric field lines being perpendicular to the surface. Also, some students used expressions such as “piercing through,” “being powerful,” and “carrying electricity” for electric field lines. This indicates that the students confused the concept of the electric field with electric current. The fact that they believed electric field lines could interact with the object indicates their belief in electric field lines being real.

The Findings Related to Property 3: “Electric field lines are drawn from (+) charge to (–) charge”

This property related to the direction of electric field lines was examined in all three sections of the scale through six items in total. Figure 8 shows the distribution of student scores for this property by scale item.

As shown in Fig. 8, none of the students mentioned anything about the direction of electric field lines in item 1. The students showed the highest success rate ($f=25$; 71%) related to the direction of electric field lines in their drawings for 2A. However, the number of students who made the correct drawing for the direction of electric field lines in 2B was 9 (26%). Only 2 students (6%) made the correct drawing for 2C. In 3A which included a false drawing, 12 students (34%) mentioned that the direction of lines was wrong. The total score for property 3 was 63 for the entire scale, whereas the success rate was 30%.

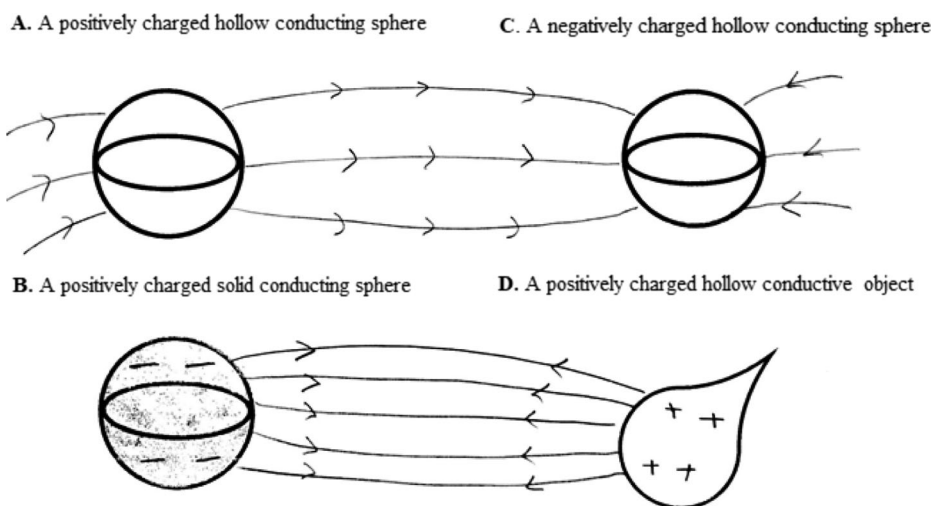
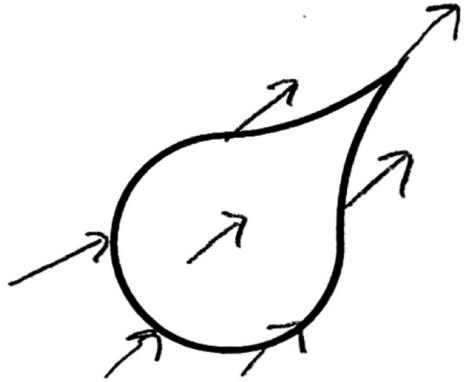


Fig. 7 The distribution of student scores for property 1 (Electric field lines are perpendicular to the surface) by scale item

Fig. 8 The distribution of student scores for property 3 (Electric field lines are drawn from (+) charge to (−) charge) by scale item



There were various mistakes in the drawings of students regarding this property. S1 and S3 made similar mistakes in their drawings. Figure 9 shows the drawing made by S1. When asked to explain his drawing, S1 said the following:

S1: It is similar to a magnet, the lines enter from one end, and exit from the other. I drew it like that.

It was noted that 12 students (34%) combined two objects when drawing (Fig. 10). It was remarkable that the students put a (−) sign even though it was stated that the object was positively charged in 2B. In spite of this, they drew electric field lines as arrows moving in both directions. Among these students, S19 and S26 gave the following answer when asked about their reasoning:

S19: I combined the two objects, because lines need to exit from one and enter into the other. It is not possible to draw them separately! If it starts in this one (shows the object on the left), it must end in this one.

S26: How else can you draw it? It is not possible to draw them individually, so I combined them.

This may be interpreted as that the students knew the property that “Electric field lines are drawn from (+) charge to (−) charge.” However, the inconsistent direction of lines in the drawings makes it difficult to come to this conclusion.

Fig. 9 The drawing of student coded S1



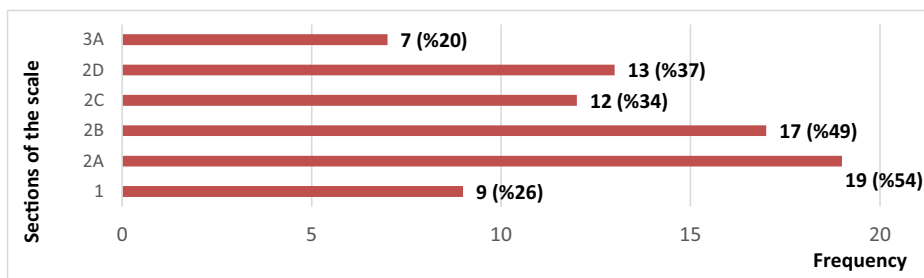


Fig. 10 The drawing of student coded S19

Another interesting drawing was made by S6. This student drew the electric field lines for the spheres correctly; however, he made the drawing given in Fig. 11 for the teardrop-shaped object. When asked about his reasoning, the student gave the following answer:

S6: I need to draw the lines from one end to the other. The other objects are spherical, they have no ends, so the lines are drawn outward. Because this one has an end, I need to draw the lines toward the end.

In light of the findings, it is possible to say that the students confused electric field lines with magnetic field lines. Also, the students were observed to not fully understand the direction of electric field lines and made random drawings. Some sentences used by the students in interviews indicate that some students understood the proper direction of the electric field and had the knowledge required to draw them; however, they did not understand what this direction was. The students especially did not know the concept of “charge at infinity.”

The Findings Related to Property 4: “Electric field lines are denser at pointed ends of a conductor

This property related to the density of electric field lines was examined in all three sections of the scale through four items in total. Figure 12 shows the distribution of student scores for this property by scale item.

As shown in Fig. 12, none of the students mentioned anything about electric field lines being denser at pointed ends of a conductor in item 1. Nine students (26%) made the correct drawing for 2D. For 3A and 3B, on the other hand, none of the students mentioned this property. The total score for property 4 was 9 for the entire scale, whereas the success rate was 6%.

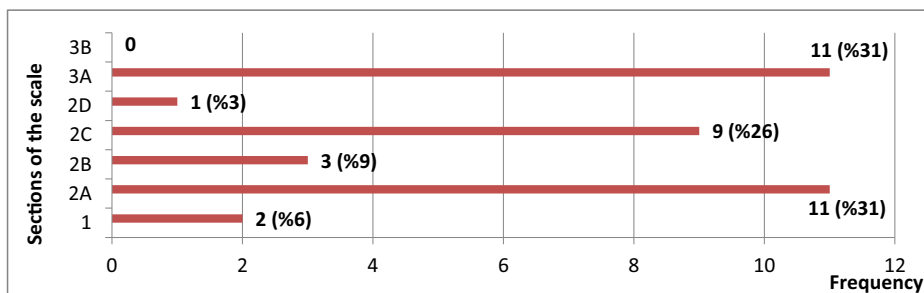


Fig. 11 The drawing of student coded S6

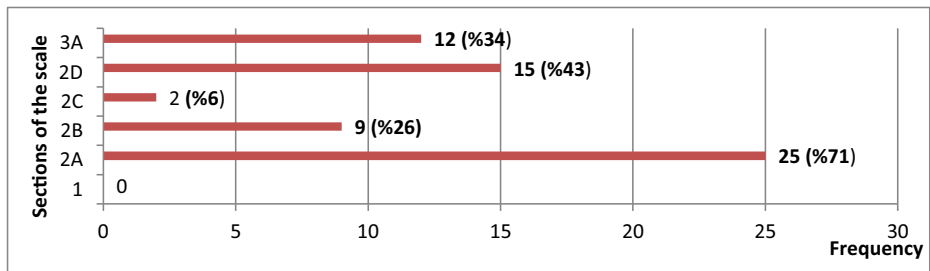


Fig. 12 The distribution of student scores for property 4 (Electric field lines are denser at pointed ends of a conductor) by scale item

The student drawings for spherical objects involved homogeneous field lines (Fig. 13). The students tended to draw homogeneously distributed field lines for the teardrop-shaped object as well. When asked about their reasoning, the students gave the following answers:

S15: I remember you saying lines would be denser at pointed ends; but I guess I did not understand that it would mean drawing more lines at pointed ends.

S5: Is the electric field the same everywhere? Maybe it is. It may be more at some places, the object may conduct the electricity more at some places. Then it is possible to draw more lines. But how can we understand this from the shapes?

S14: (points to his drawing) Like this, the field is distributed to everywhere. Why would it gather at a certain place? Is there a force there?

S26: It may be possible to draw more lines at points with higher conductivity, but I do not know. It has nothing to do with the objects round or pointed shape.

Based on the findings obtained from interviews, it is possible to say that the students confused the concept of the electric field lines with electrical conductivity. Rather than pointed ends, the students suggested that electric field lines would be denser at points with higher electrical conductivity. It was concluded from these statements that the students did not understand the nature of the electric field and believed that the lines were real.

The Findings Related to Property 5: “Electric field lines do not intersect”

This property related to the direction of electric field lines was examined in all three sections of the scale through six items in total. In the second section of the scale, extra attention was paid

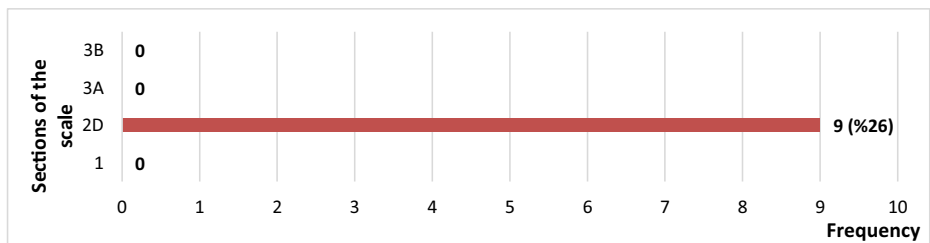


Fig. 13 The drawing of student coded S15

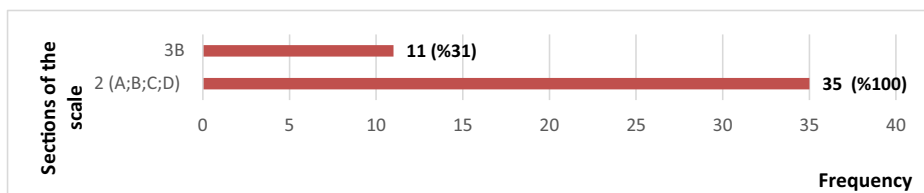


Fig. 14 The distribution of student scores for property 3 (Electric field lines do not intersect) by scale item

to the use of this property. Figure 14 shows the distribution of student scores for this property by scale item.

As shown in Fig. 14, 11 students (31%) realized that electric field lines intersected in 3B, and stated that this was false. In all drawings for 2A, 2B, 2C, and 2D, the students drew electric field lines without any intersections. The total score for property 5 was 151 for the entire scale, whereas the success rate was 86%.

When shown false drawings and asked what was wrong with these, the students gave the following answers:

S12: (pointing to 3B) These edges face each other. Lines must intersect. They cannot be drawn without intersections.

S19: It made me uncomfortable that the charges moved with such turbulence. They must move in a uniform manner. They intersect due to the turbulent motion.

S20: Electric field lines do not intersect. They must be in a round formation. They cannot be drawn as arrows.

S27: Because negatively charged objects do not conduct electricity. (pointing to intersecting lines above the heart-shaped object) Arrows drawn like this are false. They should not have been drawn like this. They should have moved straight.

S30: Conductors do not intersect and move in a straight direction. All lines should have been drawn in a straight direction.

Based on the findings obtained, it is believed that the students saw electric field lines for spherical objects in their textbooks and classes; hence, they were not sure about how to make a drawing for a differently shaped object. It was observed that the heart-shaped object confused the students in particular. It was also remarkable that the students used phrases such as “arrows,” “charges,” and “conductors.”

Conclusion and Recommendations

Figure 15 shows the overall success rate related to the properties of electric field lines. According to the chart, the most commonly reflected property by the students was property 5, “Electric field lines do not intersect.”, with 86%. The success rate of the students was 36.67% for property 1 (The electric field within the conductor is zero), 15% for property 2 (Electric field lines are perpendicular to the surface), and 30% for property 3 (Electric field lines are drawn from (+) charge to (−) charge). The lowest success rate (6%) was seen for property 4 (Electric field lines are denser at pointed ends of a conductor).

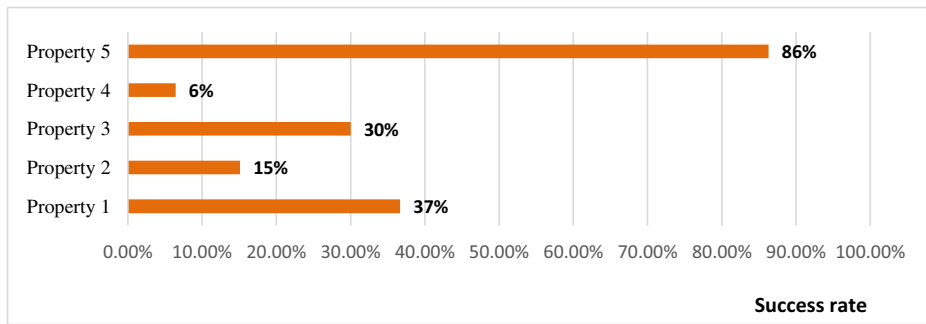


Fig. 15 The distribution of success rate by property

A remarkable finding of the study was the low success rate of the students for all properties in item 1, “Please write the properties of charged conductors at electrostatic equilibrium.” However, the students reflected some properties which they had not mentioned in item 1 in their drawings. As noted in the literature, this was an example for cases where the drawing method is more effective than writing to reveal knowledge, and where students feel more comfortable expressing themselves by drawing (Ayas 2006; Rennie and Jarvis 1995; Thomas and Silk 1990; White and Gunstone 1992).

The findings of the study showed that the students knew certain properties of electric field lines; however, they were not able to make sense out of them. When asked to explain their drawings, it was observed that the students knew that the electric field was zero within the conductor; however, they were not able to reflect this knowledge in their drawings. In various drawings, the students tried to draw electric field lines on the surface of the given object. We believe that the reason behind this was their lack of knowledge as to why the electric field is zero within the conductor. Similarly, Garza and Zabala (2010) found that students had difficulties in understanding the charge distribution on conducting objects. Another reason behind this was observed to be students confusing the electric field with concepts such as charge and the magnetic field, which is consistent with findings in the literature (Maloney et al. 2001; Planinic 2006; Saarelainen et al. 2007).

The fact that the students confused electric field lines with magnetic field lines indicates that the students did not fully understand the direction of electric field lines, and made random drawings. Some sentences used by the students in interviews indicate that some students understood the proper direction of the electric field and had the knowledge required to draw them; however, they did not understand what this direction was. Garza and Zabala (2010), too, found that students drew field lines randomly without paying attention to the object’s charge. In this study, it was seen that some students tried to draw electric field lines similar to magnetic field lines between the ends of a magnet. Another interesting point was that the students did not know the concept of “charge at infinity,” and needed a charged object nearby to end electric field lines. The reason behind this may be explained as they perceived the charge as the source of the electric field, and thought that there would be no electric field without charge (Bohigas and Periago 2010; Furió and Guisasola 1998; Velazco and Salinas 2001). Chabay and Sherwood (2000) note that it is not possible to understand the field concept without

understanding the charge concept. Based on this idea, it may be concluded that all incorrect drawings at every stage of the study arose from the students' lack of a sound understanding related to the charge concept. It was observed that the students failed to make necessary connections between charge and electric field. We believe that when these students learn that the electric field arises from the electric charge, most of their common mistakes will disappear.

Another finding was that the students mostly confused the electric field with the electric current, which is similar to the findings obtained by Chen and Kwen (2005). The students confused electric field lines with electric current; hence, they looked for a current on the object. Some students stated that electric field lines carried electric current. Some others tried to explain their incorrect drawings with the conductivity concept. Since the objects given in the data collection tool were conductors, they expected electric field lines to behave as electric current. Rather than pointed ends, the students suggested that electric field lines would be denser at points with higher electrical conductivity.

The least commonly known property among the high school students was found to be "Electric field lines are drawn perpendicular to the surface." The students used expressions such as "piercing through" and "being powerful" to explain their drawings. It was also remarkable that the students used phrases such as "arrows," "charges," and "conductors." Studies in the literature show that students prefer phrases used in everyday life instead of scientific statements, which is suggested to be one of the most important factors that affect their understanding (Akdeniz et al. 2000; Bak et al. 2005; Duit and Rhoneck 1997). Similarly, Duit and Rhoneck (1997) examined misconceptions related to the electricity, and found misconceptions to arise from differences between everyday language and concepts used in physics. The role of everyday language in incorrect explanations of the students regarding their drawings was evident in our study as well. This caused the students to believe that electric field lines interacted with the object, and they tended to concretize electric field lines. Based on this finding, it can be said that the students did not understand the vectorial nature of the electric field, and believed that electric field lines were real. In this sense, it can be said that the findings of the present study are similar to those in the literature (Bradamente et al. 2007; Povoci and Finley 2002, 2003, 2007; Saarelainen et al. 2007). Also, there is a similarity with research findings which suggest that students have difficulties in defining the electric field (Bohigas and Periago 2010; Bradamente et al. 2007; Furió and Guisasola 1998; Martín and Solbes 2001; Saarelainen et al. 2009).

Understanding the electric field is important to understand the magnetism field, which is taught later on. Therefore, we believe that ensuring students understand the definition and the vectorial nature of the electric field will prevent possible future challenges. Students may be shown how to draw electric field lines for objects with different shapes. Reasons behind these drawings may be discussed.

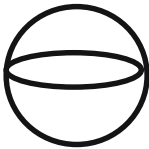
The interview findings of this study belong to the students who made incompatible drawings with the literature. The limitation of this study is that it does not show that the students who made correct drawings exactly know the characteristics of the electric field lines. The students who made correct drawings may understand and remember the subject, but they may also remember the image in the textbook only. The drawing method used in the study presents a picture of the students' minds but does not give a clear picture of how much they know. Therefore, it is recommended that future studies should use another measurement tool besides the drawing method.

Appendix: Electric Field Lines Drawing Scale

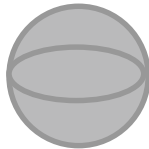
Section 1 Please write the properties of charged conductors at electrostatic equilibrium.

Section 2: Loaded conductive objects with electrostatic equilibrium are given below. Please, draw the electric field lines for these objects.

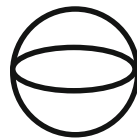
A. A positively charged hollow conducting sphere



B. A positively charged solid conducting sphere



C. A negatively charged hollow conducting sphere



D. A positively charged hollow conducting teardrop-shaped



Section 3: The electric field lines of charged conductive objects in electrostatic equilibrium are given below. If these impressions are correct, check True. If it is incorrect, mark the Wrong and specify where the error is.

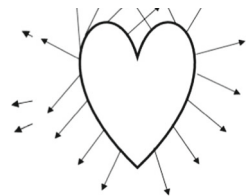
☒ Correct

☐ Incorrect

The error/s is/are

.....

A positively charged hollow conducting heart-shaped



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