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Examination of prospective teachers' knowledge about capacitors and electric field lines

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ABSTRACT

Purpose: The aim of this study is to investigate the knowledge of prospective physics teachers on capacitors and electric field lines. **Sample:** The study group consists of 45 prospective physics teachers, 31 of whom are female, 14 of whom are male, studying at a state University in Turkey. **Design and methods:** A descriptive model was selected as the method of the research. The data of the study were collected through a measurement tool and semi-structured interviews prepared by the research. The measurement tool consists of open-ended questions and drawings. The answers received from the prospective teachers were subject to descriptive analysis. **Results:** The findings showed that prospective teachers had sufficient knowledge of the definition, function, and structure of the capacitor. However, it was determined that there were difficulties in understanding the source of the loads in the capacitor plates. Furthermore, although they knew the definition and structure of dielectric, their knowledge of the function of dielectrics was not based on a scientific basis. The prospective teachers were unable to establish a connection between the dielectric and the electric field. They have also been found to confuse electric field lines with electric current and magnetic field lines. The prospective teachers often drew point charges for the electric fields between the capacitor plates. It has also been found that they think electric field lines are real.

KEYWORDS

Capacitor; electric field lines; prospective teachers

Introduction

An introductory electric and magnetism course will generally start with teaching field lines. The electric field lines are a model used in teaching the concept of electric field. Niccolo Cabeo first described the concept of field lines in *Philosophia Magnetica*, which was published in 1629. Later, it was adopted by Faraday in the 1820s, independently. 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' (Feymann, Leighton, and Sands 2016).

In order to teach the subjects of electricity and magnetism, students must first fully understand the concept of electric field. The concept of electric field is very important because it is the 'backbone' of the concept of electricity (Samsudin et al. 2015). However in most studies, it is seen that students do not have a clear understanding of electric field. Students do not make a clear distinction among the concepts of electric field, electric field lines, and electrical force (Planinic 2006; Pocovi 2007; Pocovi and Finley 2002; Saarelainen, Laaksonen, and Hirvonen 2006). It is determined that students were not able to distinguish between electric field and electric force in the studies. Also, students have a tendency to use the concept of electric force instead of electric field (Bilal and Erol 2009; Furió and Guisasola 1998; Martín and Solbes 2001). There are various studies that indicate that students incorrectly interpret electric field lines and confuse the electric field with magnetism (Maloney et al. 2001; Planinic 2006; Saarelainen, Laaksonen, and Hirvonen 2006). Similarly, science teachers failed to distinguish electric field and magnetic field (Hekkenberg, Lemmer, and Dekkers. 2015). The concept of electric field is also often confused with electric current (Chen and Kwen 2005; Taşkın and Yavaş 2019).

The literature points to misunderstandings about electric field lines and electric field vector as the reasons for learning difficulties in electrical subjects (Saarelainen, Laaksonen, and Hirvonen 2006; Törnkvist, Petterson, and Tranströmer 1993). For example, in the studies that were conducted, it was determined that the origin of the learning difficulties experienced in the subjects of Gauss's law (Singh 2006), Coulomb force (Saarelainen, Laaksonen, and Hirvonen 2006; Viennot and Rainson 1992), and magnetism (Furio and Guisasola 1998) stemmed from the misunderstanding of electric field lines. The students' inability to establish a connection between Newton's laws and electric field has been shown to be the reason for the difficulties students experience in learning the concept of electric field (Dunn and Barbanel 2000; Furio and Guisasola 1998). It was observed that this problem disappeared when the concept of field was introduced with the help of field lines (Melo-Niño, Cañada, and Mellado 2017). Similarly, Sefton (2002) also stated in his study that explaining simple electric circuits together with electric field lines would prevent many misconceptions. He suggested that the energy transfer with cables should be taught together with electric field and magnetic field.

While it is very important to understand electric field lines correctly, it is known that students have difficulty in learning electric field lines. The literature shows that students perceive electric field lines as if they actually exist (Galili 1993; Povoci and Finley 2002; Taşkın and Ünlü Yavaş 2019). It was determined that the students thought that the force only acts on the part where the electric field lines are drawn, and there is no electric field in the spaces between the lines (Bilal and Erol 2009; Pocovi and Finney 2002). Students have the idea that electric field lines start and end anywhere and electric field consists of a limited number of lines (Rainson, Transtromer, and Viennot 1994; Maloney, O'kuma, and Hieggelke 2001).

When the studies in the literature are examined, it is seen that there are general studies on the knowledge of students about the concept of electric field. Electric field lines, on the other hand, have been included in a small portion of these studies or not at all. There are limited number of studies focusing specifically on students' understanding of electric field lines. In these studies, it is generally observed that the properties of electric field lines are given in terms of the force acting on the charged particle in the electric field (Saarelainen, Laaksonen, and Hirvonen 2006; Povoci and Finley 2002). Apart from these, Törnkvist,

Petterson, and Transtömer (1993) focused on understanding electric field lines between charged conductors; Taşkın and Yavaş (2019) focused on understanding electric field lines of conductors in electrostatic equilibrium.

Capacitors are also one of the topics built on electric field. Saarelainen, Laaksonen, and Hirvonen (2006) pointed that a theoretically more powerful concept of electric field would seem to provide a better background for studying subjects of capacitance. The findings revealed in the study of Eylon and Ganiel (1990) that the students not being able to connect with the electric field by charging the capacitor is an example of this situation. However, there is no study focusing on understanding the electric field of capacitors in the literature. Kesonen, Asikainen, and Hirvonen (2011) investigated the properties of electric field lines between capacitor plates in only one item of the scale they used in their studies.

Considering that the understanding of electric field lines is of great importance in the teaching of all electricity and magnetism subjects, it is thought that a study examining the deepening of electric field lines of capacitors will make an important contribution to the literature. Therefore, this study focused only on capacitors. Besides the structure and function of capacitors, students' thoughts on electric field lines between capacitor plates were investigated for different types of capacitors. In addition to open-ended questions and interviews, the method of drawing was also included in the study to enable students who do not like to answer questions and have difficulty in expressing their thoughts verbally (Rennie and Jarvis 1995; White and Gunstone 1992).

Method

To investigate the students' knowledge of capacitors and electric field lines, a descriptive survey model, which is one of the qualitative research methods, was used in the study. In this model, the aim is to investigate the current situation in a subject (De Vaus 2001). The situation is defined and its relationship with other situations is examined (Cohen, Manion, and Morrison 2009). Descriptive survey model authorizes organizing the data according to the themes revealed by the research questions (Hesse-Biber and Leavy 2011). Thus, it provides in-depth information on any subject and can be the basis of research with the question of why (De Vaus 2001). In descriptive studies, while trying to describe the qualities related to the case studied, it is attempted to reveal the attitudes or opinions of the individuals participating in the research without providing any input on them (Borg, Gall, and Gall 1993; Creswell 2008; Robson 2017).

Study group

During the selection of the prospective teachers for the study group, it was necessary to ensure that they had taken the Electric course first. These prospective teachers confirmed that they had learned and remembered the subjects of 'electric field', 'electric field lines' and 'capacitors' in the lecture. Those who said they did not remember the subjects were not included in the study group. The study group consisted of 45 prospective physics teachers, 31 of whom were female, 14 of whom were male, studying at a public university in Turkey. The average age (min = 20, max = 25) was 22.

Data collection tool

The data were collected in two stages. In the first phase, a scale consisting of two parts was used for data collection. The following questions were asked open-ended as the first part of the scale:

- Write down the properties of electric field lines.
- What is a capacitor? How is its structure?
- How are capacitor plates charged?
- What is a dielectric, what does it do?

In the second part of the scale, four diagrams were presented to the prospective teachers who were then asked to draw appropriate electric field lines on each diagram. These diagrams were: (A) parallel plate capacitor, (B) spherical capacitor, (C) cylindrical capacitor, and (D) dielectric capacitor (Figure 1). The suitability of these diagrams for use in this study was agreed upon after consultation with two physics experts.

In the second phase, semi-structured interviews were conducted. The interviews were conducted at a physics laboratory. The duration of the interviews varied between 25 and 35 min. In the interviews, the prospective teachers were asked questions on the first part of scale again.

Also, they were asked to explain their drawings and answer questions about their drawings. The researcher firstly tried to understand the drawings without interfering with the perception of prospective teachers. In order to avoid potential misvaluations caused by the drawing, the features seen in the drawings were confirmed. The diagrams in which interesting drawings were made were focused on. The detailed questions about the characteristics of the electric field lines, the vector representation, and the electric field concept were developed according to their answers. The notes taken by the researcher during the interviews were read again to the students and their approvals were obtained.

Data analysis

Descriptive analysis method was used in the analysis of the data. Evaluation of open-ended questions and drawings was done in different ways. In the first phase, open-ended items in the first part of the scale were evaluated, while a four-point criterion was used for the responses to each item. These criteria have been in the form of 'adequate explanation'

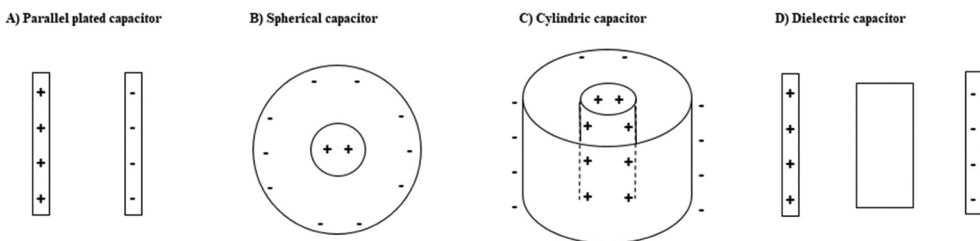


Figure 1. Four diagrams in the second part of the scale.

(AE), ‘partially adequate explanation’ (PAE), and ‘scientifically erroneous explanation’ (SEE) and “no explanation” (NE).

The properties of electric field lines that constitute the subject of the research and the information on which part of the scale was investigated are summarized in Table 1. While evaluating the drawings, a different path than the above was followed, and the data obtained from the drawings were digitized by scoring. If a required property (P1-P4 in Table 1) was found in the teacher’s response, a score of ‘1’ was awarded. P4 was excluded from the research findings as it could not be investigated in the drawings. Two physics education experts scored independently, and then discussed their differences of opinion. Then, the total score was calculated. The numerical data were presented in the findings with the help of graphics.

Some of the drawings among answers of the prospective teachers that reflect the properties in the Table 1 are shown in the Figure 2. These model answers received full points in the evaluation, and it was confirmed in the interviews that they were based on correct information. In addition to the three properties in the table, the prospective teacher who made the drawing in Figure 2(a), electric field lines properly in the middle of the plates, showed they become more widely spaced as they approach the edges. It also continued the electric field lines on the outer part of the plates. The prospective teacher who made the drawing in Figure 2(d), also showed that an electric field in the opposite direction occurred in the dielectric. Of course, it should be remembered that even in these model drawings, field lines do not start and end on charges.

Content analysis was used in the analysis of findings from interviews. The type “coding according to the concepts extracted from the data” was used in categorizing the data (Yıldırım and Şimşek 2013).

Table 1. Distribution of properties of electric field lines according to scale items.

Property Number	Property	Scale parts of the feature	Highest score possible
P1	Electric field lines are perpendicular to the surface.	1, 2A, 2B, 2 C, 2D	5
P2	Electric field lines are drawn from (+) charge to (–) charge.	1, 2A, 2B, 2 C, 2D	5
P3	No two field lines can cross.	1, 2A, 2B, 2 C, 2D	5
P4	Electric field lines are denser at pointed ends of a conductor.	1	1

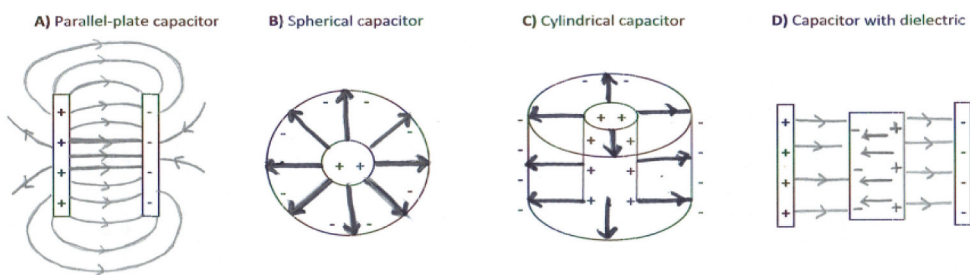


Figure 2. Model answers.

Tracy (2010) proposed eight criteria for judging the quality of qualitative research: worthy topic, rich rigor, sincerity, credibility, resonance, significant contribution, ethics, and meaningful coherence. In the previous sections, some criteria were attempted to be met by giving detailed information about each step of the study (i.e. the worthiness of topic, rich rigorousness, sincerity, and ethicality). Credibility, resonance, significant contribution, and meaningful coherence are to be explained here for further attention.

Attempts to establish credibility were made through the use of thick description member checking, and multiple meanings of participant quotations. All the participants were included in the interviews. Also, data were collected by more than one data collection tool. Different features (verbal expression, open-ended questions, drawings) were included in the data collection tools so that students could express themselves comfortably.

In the attempt to promote resonance, data were presented using rich quotations in the hope of reflecting the structure of opinion of participants to emerge vividly. In order to avoid the misinterpretations that may arise from the drawings, the prospective teachers were asked questions about drawings and the reasons why they drew their drawings in the way they did were confirmed. The results were shared with the prospective teachers after the analysis and participant confirmation was provided.

In evaluating the significance of contribution of the research, one might consider the theoretical (e.g. implications for conceptual understanding), and practical (e.g. using for teaching electric concepts) significance of the findings. In terms of meaningful coherence, it is thought that the study achieved its purpose, used methods that matched the research paradigm. In addition, efforts were made to link research foci, methods, and findings with the existing literature.

In addition to Tracy's criteria, the research data were coded independently by the two experts. The formula ' $\text{Reliability} = \text{Consensus} / (\text{Consensus} + \text{difference of opinion})$ ' has been used (Miles and Hubermann 1994). 96% accord was achieved as a result of this process. The concepts and themes emerging from the raw data are presented in the findings section without adding comments.

Findings

Findings from open-ended questions

The prospective teachers were first asked about the properties of electric field lines. 40 (89%) of prospective teachers said that electric field lines were drawn from (+) charge to (–) charge. 39 of them (87%) said that electric field lines are denser at pointed ends of a conductor; 27 (60%) said they were drawn perpendicular to the surface; 15 (33%) said no two field lines can cross each other (Chart 1 1). Further discussion of the prospective teachers' understanding of electric field lines will be given in the section on the results of the drawings.

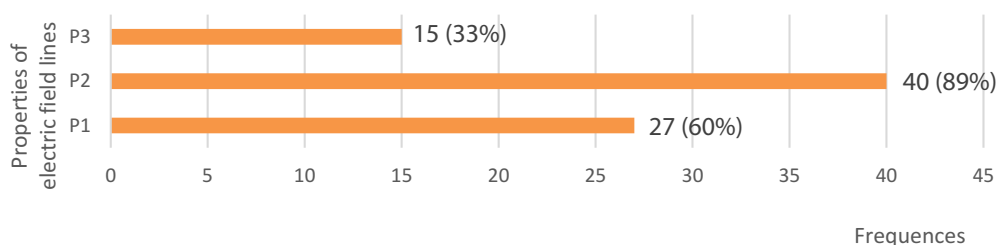


Chart 1. Distribution of scores for properties of electric field lines.

The frequency and percentage values of the answers from other open-ended questions are presented in Table 2. For definition and structure of capacitor, all prospective teachers gave adequate explanation.

For sources of charges in capacitor plates, they made the scientifically erroneous explanation although the majority of the prospective teachers ($f = 38$; 84.4%) accepted that the RC circuit was similar to an open circuit. The distribution of these incorrect answers is as follows: six prospective teachers stated that the battery created a conduction current from the (+) pole to the (-) pole. Thirteen stated that the plates were charged by the battery because they were connected to the battery. For example, T18 said: *"The plates are connected to the battery. The charge passes from the battery to the plates. It is charged with (+) connected to (+) and with (-) connected to (-)".* 18 prospective teachers stated that the plates were charged by induction. One of these prospective teachers, T7 said: *"First, charges come out from the (-) pole of the battery and charge the plate (-). Then, it pushes the (-) charges on the opposite plate away. Thus, the plate is charged with (+) charge."* 7 prospective teachers tried to explain the charges on the plates with the electric field between the plates, and stated that the plates were charged as a result of the movement of the charges. The explanation of T44 is as follows: *"When it is connected to different poles of the battery, an electric field occurs in between. Opposite forces act on the charges. Positive charges are transferred to one plate, negative charges to the other plate".* Considering the total, the correct answer could not be obtained from this question. Most of the prospective teachers did not mention the electric field between the capacitor plates. It was observed that those who mentioned did not understand the variable nature of the electric field, did not associate the charging of the plates with this issue.

When asked about the structure of the dielectric, all of the prospective teachers made an adequate explanation by saying *"insulator"*. When asked about the role of the dielectric, the majority ($f = 34$, 76%) made an adequate explanation. The answers given to this question were, respectively, increasing the capacitance (96%), providing mechanical

Table 2. Distribution of answers from open-ended questions.

Question	AE		PAE		SEE		NE	
	f	%	f	%	f	%	f	%
Definition of capacitor	45	100	-	-	-	-	-	-
Structure of the capacitor	45	100	-	-	-	-	-	-
Source of charges in capacitor plates	-	-	2	4.4	38	84.4	5	11.1
Structure of dielectrics	45	100	-	-	-	-	-	-
Role of dielectrics	11	24	34	76	-	-	-	-

support (87%), increasing the maximum operating voltage (22%). It was seen that these expressions, which were also found in the textbooks, were remembered by the prospective teachers.

In interviews, 43 prospective teachers who answered 'dielectric increased the capacitance' were asked how dielectrics did it. The correct answer was not received from the prospective teachers. 31 prospective teachers (69%) did not answer the question. 9 (20%) tried to explain this by increasing the total surface amount and 6 (13%) by the charge interaction between the dielectric and the capacitor plates. The description of T8 is as follows: *"The interaction between the conductive plates and the dielectric happens. The (+) charged plate attracts the (-) charges on the side of the dielectric close to itself. Polarization happens on the dielectric. Thus, the amount of charge increases and the capacity increases."*

These findings suggest that prospective teachers may not fully understand the function of dielectrics. The prospective teachers were unable to establish a connection between the dielectric and the electric field. Although all prospective teachers know that dielectric is non-conducting material, it has been observed from their explanations about its role that they associated the dielectric with the charge movement on the dielectric and polarization.

Findings from drawings

Electric field lines of parallel plate capacitor

When the drawings for a capacitor with a parallel plate are evaluated, the distribution of the drawings according to the properties of electric field lines is seen in [Chart 2](#).

Various errors were found in the drawings. The drawings in [Figure 3\(a\)](#) show that electric field lines are drawn towards the plates at the top of the capacitor plates. The prospective teacher T19 who made the drawing explained his drawing as follows: *"Since the plates are charged, there are electric field lines not only between them but in all directions. There are also lines from other charges at the ends."* This answer suggests that the prospective teacher knows the concept of "charge at infinity" and remembers drawings of electric field lines of point charges. Although the prospective teacher T19 drew very close to the truth, his statement shows that he did not adequately understand the electric field between the plates.

Prospective teachers with T2 and T25 codes made similarly incorrect drawings. In this drawing, it is seen that the electric field lines are drawn into the plates and that '0' is written between the plates. T2 expressed his drawing as *'because the charges are collected*

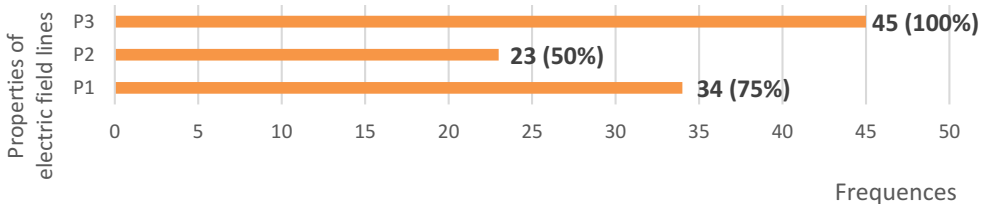


Chart 2. Distribution of scores for parallel plate capacitor according to electric field lines properties.

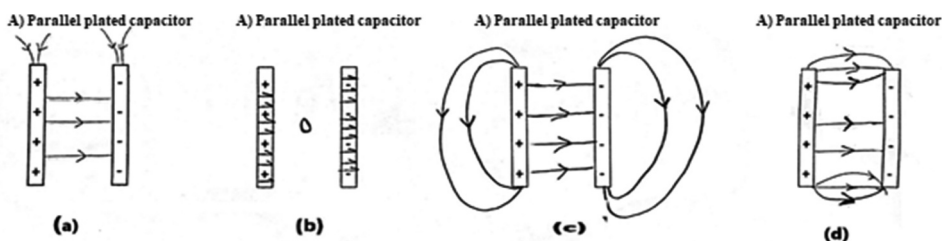


Figure 3. Incorrect drawing examples of parallel plated capacitor.

on the surface, the electric field inside becomes zero.' It is seen that these prospective teachers perceived capacitors as conductors in electrostatic equilibrium due to their plates being conductors and made similar drawings.

The drawing seen in Figure 3(c) was seen in the answers of prospective teachers with the codes T12, T21 and T41. Here it is seen that the top and bottom ends of the plates are joined together. In a common phrase, these prospective teachers explained their drawings in the interviews as "Electric field lines are drawn in the form of closed rings". It is understood that the prospective teachers were not able to distinguish the electric field lines from the magnetic field lines.

A similar error in Figure 3(d) was seen in the drawings of prospective teachers with the codes T6, T9, T13 and T35. Although each of them produced a drawing that was very close to correct, when explaining their drawings in the interviews, T13 and T35 express their drawings as "have more electric field lines at the ends". It was seen that these prospective teachers thought capacitor plates as a pointed object and did not understand why the electric field lines are denser at the pointed ends of a conductor.

Electric field lines of spherical capacitor

When the drawings for a capacitor with spherical plate are evaluated, the distribution of the drawings according to the properties of electric field lines is seen in Chart 3.

Some errors are seen from drawings of the prospective teachers. For example, the drawing seen in Figure 4(a) was made by four prospective teachers. T4, who made one of these drawings, explained his drawing as follows in interviews:

T4: "Field lines do not depend on the shape of the plates. It just depends on the charge. It is important to draw from (+) to (-). They go the shortest way, straight drawn, so that they don't intersect, and they carry a current."

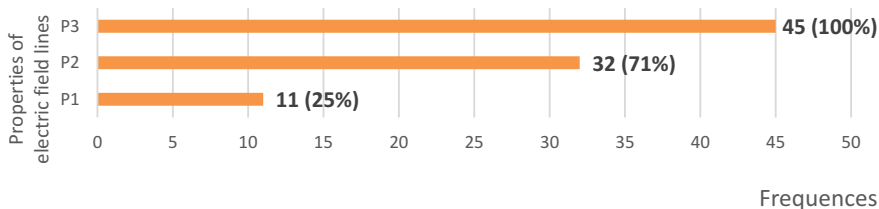


Chart 3. Distribution of scores for spherical capacitor according to electric field lines properties.

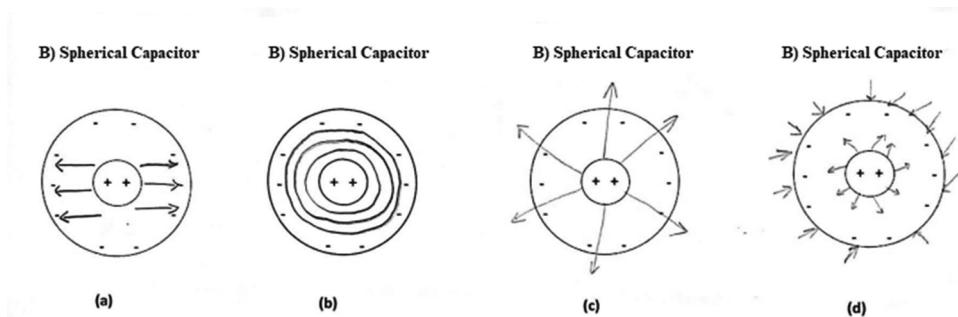


Figure 4. Incorrect drawing examples of spherical capacitor.

When we look at these statements, it is seen that the prospective teacher T4 was not aware that electric field lines should be drawn perpendicular to the surface. It is understood that this prospective teacher knew the direction of electric field lines and that they should not intersect. However, she seemed to remember them from the pictures in the book or to have memorized them without understanding the reason. Also, phrases such as 'carry the current' and "prefer the shortcut" used by the prospective teacher are thought to confuse electric field lines with electric current.

The drawing in Figure 4(b) was made by six prospective teachers in different classes. Prospective teachers T12, T17 and T42 explained their drawings as follows:

T12: "We draw electric field lines in such a way that they surround the capacitor surface, confining the surface into it. Then we calculate using the sphere formula."

T17: "We draw flat ones with flat plates. We also draw round ones with round plates. It's like a water wave, you know when you hit it with a finger and it's a round wave? This also produces a round electric field because it is round."

T42: "The charges are collected on the surface as the capacitor plates are conductive. In the capacitor, the electric field becomes zero. Since the charges are of the same type, they push each other, so a sphere-shaped electric field is formed."

The interview findings show that these prospective teachers made unscientific connections between the subject of electric field and other physics subjects they have learned. It is understood that prospective teacher T12 confused the electric field lines with Gauss surface and prospective teacher T42 confused electric field lines with conductors at electrostatic equilibrium. Also, prospective teacher T17 remembered the information about water waves. He compared the electric field with a point wave source, and said that it was produced by the plate.

The drawing in Figure 3(c) was seen on the paper of 12 prospective teachers.

Although they produced a drawing that was very close to correct, when explaining their drawings, they used the words 'we had in the book' and 'we had drawn in the lesson' to point out the electric field drawing of the point charge they learned in the lesson. The explanation of T22 is as follows: "The electric field is drawn east out of the positive charge, towards other charges. I remember when we drew it in class. Here, the inside plate is positive. It's drawn from the inside out."

The drawing in Figure 4(d) was made by four prospective teachers. T27, one of them, recalled the drawings in the textbook and explained the drawing. Her explanation shows

that although the prospective teacher knows how to draw electric field lines for conductors in point charge and electrostatic equilibrium, she does not have a complete scientific explanation. T27 coded prospective teacher said the following for drawing: *“The electric field lines out of the charge from (+), into the charge (-). There were drawings of large and small objects in the book. I drew outward from it because the inner plate had (+) charge. The large plate had (-) charge, so drawn to enter it as well. We drew the lines like this at lessons when they were single. We didn’t draw anything intertwined, but I think it should be drawn like this.”*

Electric field lines of cylindrical capacitor

When the drawings for cylindrical capacitor are evaluated, the distribution of the drawings according to the properties of electric field lines is seen in [Chart 4](#).

[Figure 5](#) shows some of the faulty drawings for cylindrical capacitors. The drawing of the prospective teacher with T11 code is seen in [Figure 5\(a\)](#). The prospective teachers’ description of his drawing is as follows: *“Electric charges move from the inside to the outside. On the upper side there are charges that interact with the charged objects on the outside. These charges first interact with the outside, then reach the inside plate.”* The prospective teacher T11 explained the electric field lines by connecting them to the electrical charges and the interaction between these charges. Although this prospective teacher’s drawing was very close to the truth for the electric field lines of the cylindrical capacitor, it appeared that he did not fully understand the electric field between plates.

The drawing seen in [Figure 5\(b\)](#) was made by 13 prospective teachers. This drawing is reminiscent of the drawing seen in [Figure 3\(b\)](#). However, the number of similar drawings made for the cylindrical capacitor was greater than that made for the spherical capacitor. Prospective teachers T25 and T27 who made these drawings said the following for their drawings:

T25: *“The surface of the cylinder plate is circular. Charges are collected on the surface, there is no electric field in it. The charge moves around the surface in the form of circles that are lined up at the bottom. This is why circular electric field lines are formed.”*

T27: *“Because the plates are conductive, and because there is space between them, the electric flow happens on the plates’ own surfaces. This is how electric field lines are drawn according to the shape of the surface.”*

These findings obtained from the interviews show that prospective teachers T25 and T27 perceive electric field lines as charge movement and confuse them with current. It is

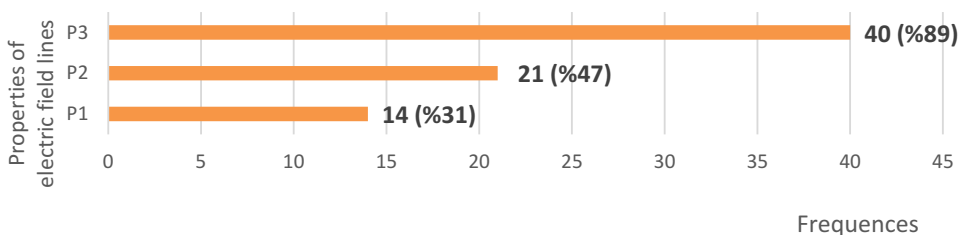


Chart 4. Distribution of scores for cylindrical capacitor according to electric field lines properties.

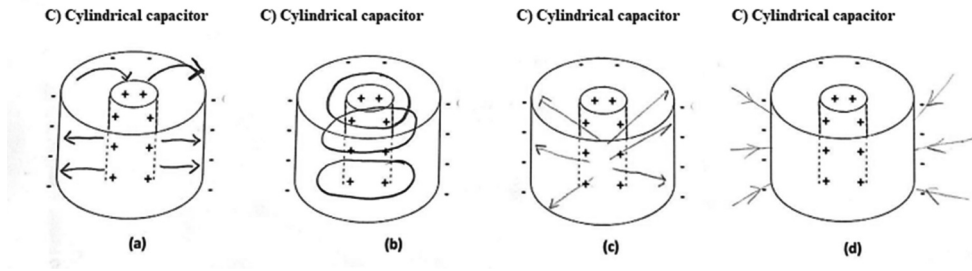


Figure 5. Examples of incorrect drawing of cylindrical capacitor.

also thought that they know that the electric field inside the conductor in electrostatic equilibrium is zero, and they try to transfer this information to the capacitors because the capacitor plates are conductive.

The drawing seen in Figure 5(c) was made by nine prospective teachers, while the drawing seen in Figure 5(d) was made by five prospective teachers. Although these drawings are different, it is seen in both that the electric field lines are oriented towards the center of the cylinder plate. The common expression in the descriptions for the drawings was that the electric charge was 'collected in the center' and 'located in the center'. It is thought that these prospective teachers are confused with the concepts of electric field and the center of mass. The following sentences were encountered in the interviews:

T22: "We have to think as if all the charges are spreading from one centre. This is the center of charge. The electric field is uniformly spread over the entire surface of the cylinder. Since the inside is (+), it spreads from the inside to the outside."

T31: "It comes from the charges outside, enters the negatively charged one because the outer plate is negatively charged. The one inside does not matter, because the priority is on the outermost one."

They first interact with the outside plate and they gather at the center of mass.

Electric field lines of the capacitor with dielectric

The distribution of the drawings for capacitor with dielectric according to the properties of electric field lines is seen in Chart 5.

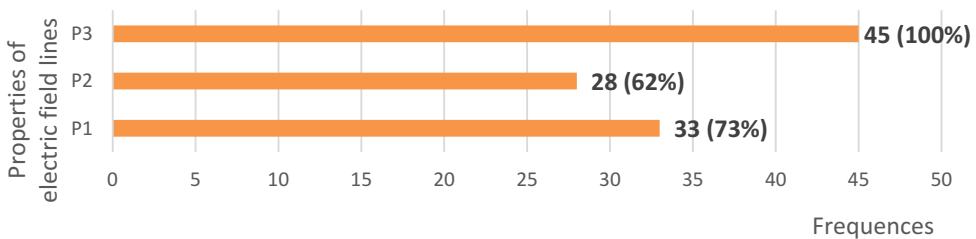


Chart 5. Distribution of scores for capacitor with dielectric according to electric field lines properties.

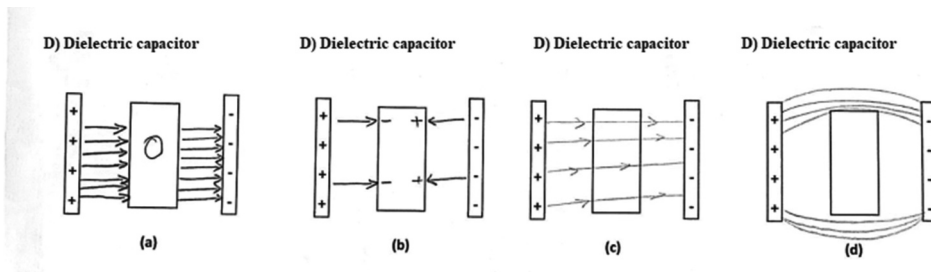


Figure 6. Incorrect drawing examples of dielectric capacitor.

The drawing in [Figure 6\(a\)](#) is on the paper of eight prospective teachers. They made a common statement as ‘the electric field in it becomes zero’ as the reason for it. Although they say that dielectric matter is an ‘insulator’, it has been a surprising finding that they make such an explanation. When these responses were recalled, they said that the capacitor plates were conductive. T23 explained it as follows: “Once the dielectric enters the capacitor, it becomes conductive. Otherwise, how would it transmit the electricity? The more conductive surface is, the more charge can be stored. So the capacity increases.”

Although the drawing seen in [Figure 6\(b\)](#) is very similar to (6a), the five prospective teachers explained their drawings as dielectric insulators. Although they did not draw an electric field line within the dielectric, they did not use an expression that there was zero in it. But interviews show that they understand electric field lines as the movement of electric charges. T11 said: “The charges on the plates close to the capacitor itself attract the opposite charges to the edges of the dielectric. Electric field is formed between these parts. Dielectric matter is an insulator. There may be an electric field in it, but it will be weak.”

The drawing in [Figure 6\(c\)](#) was made by seven prospective teachers. They explained their drawings with dielectrics being insulators. They stated that dielectric, which is an insulator, has no effect on the electric field. T20 said: “Because it is a dielectric insulator, it does not interact with electric field lines. The lines keep moving. They can decrease a little because of friction, but this decrease is not much.”

The drawing in [Figure 6\(d\)](#) was made by seven prospective teachers. They also explained their drawings with dielectricity being an insulator; unlike (5 c), they linked their explanations to the inability of the electric field to pass through the insulator. T1 said: “The insulator does not allow the electric field to carry electricity. Electric field lines also bend, passing through the non-insulating ground.”

In these statements, it was observed that the prospective teachers used phrases such as ‘interacting’, ‘passing through’, “bending”, “carrying electricity” for electric field lines. These statements indicate that prospective teachers think electric field lines are real.

Conclusion

In this study, the aim was to investigate the knowledge of prospective physics teachers regarding the properties of electric field lines between capacitors and capacitor plates. When asked about the properties of electric field lines, the least expressed feature by the prospective teachers was that the lines do not intersect each other. Despite this, it has been observed that all of the drawings reflect this property. Similar results are seen in the

study of Taşkın and Ünlü Yavaş (2019). This situation supports the findings in the literature that drawings are more effective than written or verbal expressions in revealing students' knowledge (Ayas 2006; Rennie and Jarvis 1995; Taşkın and Ünlü Yavaş 2019; White and Gunstone 1992). On the other hand, interviews have shown that some correct drawings have no scientific basis. In addition, although the most expressed property in open-ended questions is the direction of the electric field lines, it is reflected in 58% of the drawings. Similarly, the research findings of Garza and Zabala (2010) showed that students draw their field lines randomly without paying attention to the charges of bodies. For this reason, it is recommended to support the data collected by drawing method with different data collection tools.

It is seen that electric field lines are confused with other concepts in the literature. In this study, in line with the literature, electric field lines were determined by electric current (Chen and Kwen 2005; Taşkın and Ünlü Yavaş 2019), magnetic field (Hekkenberg, Lemmer, and Dekkers. 2015; Maloney et al. 2001; Planinic 2006; Saarelainen, Laaksonen, and Hirvonen 2006) and conductors in electrostatic equilibrium (Taşkın and Ünlü Yavaş 2019). Along with these, it was determined that the prospective teachers confused the electric field lines with the gauss surface and water waves.

On the subject of capacitors, it was seen that all of the prospective teachers had sufficient knowledge about the definition and structure of capacitor. Despite this, they could not make a scientific explanation about the source of the charges on the plates. Some of the prospective teachers described a current that continues throughout the circuit. The majority of them made explanations that the charges are only caused by the battery, as in Thacker, Ganiel and Boy's (1999) studies. It was observed that the prospective teachers did not notice that the electric field changed during the capacitor charging, and they could not establish a connection between the electric field and the charges. Similarly, in the literature, it was determined that the students did not use the electric field concept while explaining the charging of the capacitor (Eylon and Ganiel 1990), the motion of the charged particle in the electric field (Bilal and Erol 2009; Furio and Guisasola 1998; Martín and Solbes 2001), and the electromagnetic induction phenomenon (Thong and Gunstone 2008).

The surprising result of the study was in the findings for dielectric. Almost all of the prospective teacher have sufficient knowledge for the definition, structure, and role of dielectric. However, none of them could establish a connection between the electric field and the dielectric. A similar situation exists in the literature (Bilal and Erol 2009; Viennot and Raison 1992). In these studies, it is seen that the students think that the electric field cannot enter the insulator. In the study of Viennot and Rainson (1992), students explained this as the inability of electrical charges to move in an insulator.

Studies show that students have the following misconceptions about capacitors: 'Charges jump from one plate of the capacitor to the other', 'capacitors store a net charge', 'capacitors store voltage' (Başer and Geban 2007; Beaty 1996; Simanek 2002). These misconceptions stem from not understanding the concept of electric field. This has an effect not only on capacitors, but also on the misconceptions about electricity. For example, a common misconception about electrical circuits is called 'the attenuation model', *'electric current traveling around an electric circuit in one direction decreases gradually due to the consumption of it by devices within the circuit'* (McDermott and Shaffer 1992; Peşman and Eryılmaz 2010). It is thought that a clear understanding of the

electric field will be effective in preventing and eliminating these errors. Sefton (2002) indicated that the concept of electric field was the key to the teaching of simple circuit. In his study, he created diagrams for charge, current and electric fields in cable in circuits, and suggested that simple circuits be explained by electric and magnetic field lines. Similarly, creating diagrams in simple circuits and teaching the electric field in the capacitor can help teaching of the concept in concrete form.

Magnetic field lines can be shown to students with the help of iron powders. While showing electric field lines is a little more difficult, it can be used a petri dish containing two electrodes connected to an EHT supply and filled with vegetable oil with some semolina or grass seeds on sprinkled on to the surface. Observing electric field lines in this way will make it easier for students to understand. Instead, different methods can also be used. For example, Manunure, Delserieys, and Castéra (2020) benefited from simulations for students' conceptual understanding and decreasing their misconceptions on electric circuits. Başer and Geban (2007) determined that learning activities include analogies increased the conceptual understanding of the electric field and reduced misconceptions. Similar simulations and analogies can be developed to teach the electric field concept.

One of the main reasons that hinder the understanding of the concepts is the preference of expressions in daily spoken language for scientific concepts (Akdeniz, Bektaş and Yiğit 2000; Bak, Ayas and Devcioğlu 2005). In this study, it was observed that daily language was used quite often in the scientifically incorrect statements of the prospective teachers. These expressions, which are used instead of scientific expressions, also showed that prospective teachers perceived electric field lines as if they were in reality rather than a model. This finding is also compatible with the literature (Bradamente, Michelini, and Stefanel 2007; Galili 1993; Povoci and Finley 2002; Saarelainen, Laaksonen, and Hirvonen 2006). To prevent this, scientific concepts should be internalized by students. Methods that integrate students' knowledge with their own life experiences, such as drama and role playing, can help with this. For example, as a result of the physics lesson taught with the drama method, it was determined that prospective teachers associate concepts with daily life more and give more place to physics concepts in their speech outside of school (Taşkın and Moğol 2016, 2017). Using drama, role playing or dramatization in the teaching of the electric field subject can help students use this concept more accurately.

When the drawings are examined, it is seen that the electric field drawings between the plates of the parallel plate capacitor are closer to the line than those of the cylindrical and spherical capacitors. Drawings for cylindrical and spherical capacitors mostly resemble electric field lines of point charges. It is possible that this is due to the fact that the electric field lines of the parallel plate capacitor are shown in the textbooks, and the prospective teachers may remember these drawings. The drawings made for the capacitor types that are not included in the textbooks showed more clearly that there was difficulty in understanding the subject. For this, the electric field lines of different types of capacitors can be drawn or shown to students in the teaching of the subject.

Findings obtained in this study are limited to open-ended questions and four diagrams. In the diagrams, only the information regarding the electric field lines between the capacitor plates has been investigated. In new studies, understanding of other concepts for capacitors can be investigated. By using different measurement tools, the points that students have difficulty in understanding about capacitors can be determined.

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