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CONCEPTUAL DIFFICULTIES PRE-SERVICE PRIMARY TEACHERS HAVE WITH STATIC ELECTRICITY

Constantina G. Stefanidou, Konstantina D. Tsalapati, Anastasia M. Ferentinou, Constantine D. Skordoulis

Abstract. *Static electricity is the introductory chapter to electricity in all high school and university Physics textbooks. The interpretations of static electricity phenomena are not obvious, even in higher education. This research was conducted to identify the major difficulties which pre-service primary teachers encounter in explaining static electricity. They conducted electrostatic experiments focused on different types of electricity, in the context of an Introductory Physics Laboratory Course. The data were collected through the reports they wrote at the end of the course. The qualitative content analysis method was used in order to analyze the data. The sample, which was a convenient one, consisted of 200 pre-service primary teachers, 170 females and 30 males. The analysis showed that pre-service primary teachers have considerable difficulty conceptualizing the microscopic processes – more specifically, charging by induction – that explain these phenomena. The different roles electrons play in conductors and insulators seemed to pose difficulties for pre-service primary teachers. The findings implied an emphasis on microscopic models during macroscopic experimental processes. This could help pre-service primary teachers to understand the role of electrons in conductors and insulators and the different mechanisms involved in different types of charging.*
Keywords: *conceptual difficulties, content analysis, static electricity.*

Constantina G. Stefanidou, Konstantina D. Tsalapati
National and Kapodistrian University of Athens, Greece
Anastasia M. Ferentinou
University of Thessaly, Greece
Constantine D. Skordoulis
National and Kapodistrian University of Athens, Greece

Introduction

Electrical phenomena are an important part of the science curricula at every level of education, from primary school to university. In primary school, students are taught the concepts of charge and electrical circuits in preparation for learning and understanding more complex concepts and procedures later on relating to electromagnetic phenomena. An understanding of the basic topics of electricity - Coulomb's law, for instance, the distinction between conductors and insulators, the transfer and conservation of charge - is necessary to grasp the more abstract topics of electric potential, electric field, Gauss' law, capacitance and the propagation of electromagnetic waves (Guruswamy, Somars, & Hussey, 1997). Electricity is an area of Physics that students find significantly more difficult to understand than other areas, such as mechanics. In order to grasp electrical concepts and ideas, they should be able to relate macroscopic phenomena to microscopic procedures.

Studies of student misconceptions in electrostatics have mainly focused on electric fields and forces exerted by electric fields on charges (Eylon & Ganiel, 1990; Furio & Guisasla, 1998; Galili, 1993; Rainson, Tranströmer, & Viennot, 1994; Savelsbergh, De Jong, & Ferguson-Hessler, 2002; Törnkvist, Pettersson, & Tranströmer, 1993). The findings of these studies showed that most students do not have a clear understanding of the concept of electric field and suffer from a number of misconceptions. For instance, students have difficulties relating to the representation of electric field lines. According to Galili (1993), students believe that the line of force will be the actual trajectory of the moving charge. A straightforward interpretation of this response could be that a single line of force includes only one piece of information: the direction of the force applied on the charge. It seems as though students are being led to visualize the concept of field lines on the basis of a trajectory which is relatively more familiar. Another possible source for the confusion between trajectory and lines of force, could be a belief that lines of force are real paths of transmission for the electric effects. In addition, Törnkovist et al (1993) indicated that students think electric field lines can both cross each other and form sharp boundaries. Moreover, field lines are understood as

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isolated entities rather than a set of curves representing electric field vector as a property of space. This explains the misconceiving of electric force and electric field (field lines) as collinear vectors, regardless of the type of charge. Other misconceptions include 'field lines can begin and end anywhere' and 'there are a finite number of field lines' (Maloney, O'Kuma, Hieggelke, & Van Heuvelen, 2001; Rainson et al., 1994).

Furthermore, research into student understanding of simple electric direct current (DC) circuits showed that many students find it very difficult to apply qualitative reasoning in order to explain the observed phenomena. It is suggested that these difficulties stem from a failure to construct models of the microscopic processes that produce these phenomena (Thacker, Ganiel, & Boys, 1999).

Since electricity is used in everyday situations, it stands to reason that both students and adults suffer from multiple misconceptions as they try to understand and explain the phenomena that relate to it (Calilot & Xuan, 1993). Although textbooks begin their discussion of electricity with the concept of electric charge, students lack a clear understanding of charge as a concept (Eylon & Ganiel, 1990; Galili, 1993; Guruswamy et al., 1997; Thacker et al., 1999). Students' most typical misconceptions are that 'a neutral object has no charge' (Calilot & Xuan, 1993; Thacker et al., 1999) and, when explaining the concept of electric charge, that 'a charged body contains only either electrons or protons' (Siegel & Lee, 2001). Regarding the concept of static electricity, they believe that 'friction is the (only) cause of static electricity' (Calilot & Xuan, 1993; Siegel & Lee, 2001).

Guruswamy et al. (1997) showed that students and pre-service teachers encounter multiple difficulties relating to charge transfer in the context of static electricity. Some examples could include: 'There is no transfer of charge between two metal objects with charges of the same sign', 'Transfer between oppositely charged metal objects occurs until one of the objects is neutral', 'There is no transfer between a charged metal object and a neutral metal object', and 'The charges on the two metal objects remain the same after touching regardless of the signs of the initial charges'. Calilot and Xuan (1993) have discussed the fact that similar misconceptions are held by adults.

Moreover, Hermita et al. (2017) constructed and implemented a test to diagnose pre-service primary teachers' misconceptions about static electricity. The results included ideas such as "Electrostatic objects cannot attract neutral objects", "A neutral object is an object that does not contain an electrical charge", and "The magnitude of the tensile force between two charged objects depends on the size of the charge". Park's research was designed to identify students' prior ideas about electrostatic induction phenomena (Park, 2001). At the beginning of the interview, most of the students, both middle school and college, could predict the motion of the leaves inside the electroscope in the case of a conductor but not in the case of an insulator. Analyzing their answers, the researchers found that most students could give scientifically acceptable explanations for the phenomenon of induction in relation to conductors, but not in relation to insulators (polarization). Students could describe the conductors' induction as a result of electron transfer inside the conductor, but they had difficulties explaining the corresponding procedure inside insulators (polarization).

Regarding Greek curricula, science is included in the last two years of primary school. Primary school consists of grades 1-6 (6 to 12-year-old students). Specifically, during the fifth year, the 11-year-old students are introduced to "basic" electricity ideas and phenomena such as the atomic structure so they can understand positively and negatively electrified bodies, the three types of charging, and related phenomena such as the static and frizzy hair and how an electroscope functions. The issue under consideration is how the successful teaching of science can be ensured in primary school and pre-service primary teachers' science education has an important contribution to make here. Although a number of research projects have been conducted in the field of science education relating to electricity (Guisasola, 2014), only a few have focused on the difficulties pre-service teachers encounter with the microscopic procedures of static electricity. This is the issue under consideration in this research which, in relation to the findings in the literature, contributes to the design of appropriate teaching strategies which focus on microscopic procedures and not only macroscopic phenomena.

Purpose of the Research

This research aimed to identify pre-service primary teachers' conceptual difficulties with static electricity in the context of different types of charging. The research reported here formed part of a broader Introductory Physics Laboratory Course (IPLC), which consisted of five confirmatory laboratory exercises, one of which was on electrostatics. In respect of the research reported here, the questions were the following:

a) To what extent are pre-service primary teachers able to construct the scientific explanations relating to static electricity?

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b) Which are the conceptual difficulties pre-service primary teachers face in relation to the mechanisms by which static electricity is generated?

Research Methodology

General Background

Fieldwork was carried out in Athens, the capital of Greece, in the Department of Primary Education at the National and Kapodistrian University of Athens during the winter semester of 2017-2018.

This research is qualitative descriptive with a cross-sectional design. Researchers collected the data through a survey at one time so information would be provided about certain current beliefs (Gay, Mills, & Airasian 2012). The research aimed to identify conceptual difficulties which pre-service primary teachers face in relation to static electricity. In this sense, the research attempted to reveal the related microscopic procedures that pre-service teachers had difficulty explaining. The instrument used here was an open-ended questionnaire in which pre-service teachers could express in writing their explanations relating to static electricity phenomena. All the participants responded to the same set of questions included in the questionnaire. Both qualitative and quantitative methods are used to analyze the data.

Sample of Research

The sample consisted of 200 second year university pre-service primary teachers: 170 females and 30 males. Convenience sampling was followed in the sense that the participants were selected due to convenient access. However, they did not have the characteristics of volunteers because they had to deliver the written report anyway in order to pass the course (IPLC) in the context of existing classes.

Regarding their scientific training and science knowledge, most of the pre-service teachers admitted into the Department choose the Humanities orientation. According to the Greek curriculum, during the last two years of secondary school, students may choose their orientation (e.g. Science, Technology, Humanities). Science classes are mandatory at every grade in secondary school, except the final year for those who choose the Humanities orientation. These science classes cover subjects including the structure of the atom, static electricity, conductors and insulators. As for the academic background of the pre-service teachers, they attended an Introductory Physics Course (IPC) during the same semester as the IPLC. However, when they participated in the static electricity laboratory exercises, they had not yet been taught the corresponding theory through the IPC. Their answers were therefore taken to be independent of the IPC and to derive from either the laboratory exercises or previously acquired knowledge.

Data for this research were collected from a particular Department of Primary Education (that of the National and Kapodistrian University of Athens), so it would be difficult to generalize findings to other settings.

Procedures and Instruments

Pre-service teachers were divided into 10 teams of 20 persons whose members worked in pairs and attended the IPLC. The IPLC comprised of five rotating self-standing two-hour laboratory exercises once a week: 1) taking measurements, 2) mechanics, 3) optics, 4) static electricity, and 5) Ohm's law. Participants were provided with the background material they needed to be prepared for each lab exercise. This included the related theory and some examples. For instance, in the case of static electricity, their material included examples of charging by contact. The experiments under consideration were confirmatory in the sense that pre-service teachers had to test relatively simple hypotheses for which they were prepared. While conducting these exercises, they had to identify the experimental material: instruments, devices and everyday materials. They were informed how long each task would require so they could pace themselves, and they were encouraged to take an active role in their pairs. The teaching-learning sequence, which included the three static electricity experiments, is described in detail in Appendix I.

Regarding the research data, the 200 individual written reports, which included open-ended questions and were the final deliverable of the IPLC, were collected. The questionnaire relating to static electricity was part of the overall written report and is attached in Appendix II. It consisted of six open-ended questions relating to static electricity, in which pre-service teachers were able to express their views freely: the first four questions were about

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charging by friction and contact; the last two about charging by induction. Five out of the six questions were based on the function of the electroscope in the context of types of charging. The last question focused on polarization. All participants responded to the questions, as it was part of their final assessment (response rate 100%).

Data Analysis

Both qualitative and quantitative methods are used. Conceptual content analysis was used in order to code pre-service teachers' answers. For methodological reasons related to reliability, a prior coding of the data was conducted. Subsequently, the inductive categories were established by the first three authors-coders (Cohen's kappa 0.8), adequate according to Mayring (2000). In this case, the content unit were the answers the participants enclosed in their written reports. Quantitative steps of analysis (e.g. percentages), the so-called descriptive statistics, followed in order to quantify the findings and present a clearer picture of the conceptual difficulties (Gay et al., 2012). We used an alpha level of .05 for all statistical tests.

Research Results

Content analysis of the pre-service teachers' written reports showed that most of them were able to give scientifically accepted explanations of friction and contact charging but had difficulties when explaining electrostatic induction. Particularly:

Regarding friction and contact charging (1st Experiment: Figures 4 & 6), most pre-service teachers gave scientifically accepted explanations. In order to explain friction electricity, most of them supported the view that electrons move from one material to another, as long as the electrons are looser in one material than in the other. Regarding contact charging, pre-service teachers could easily describe the mechanism through which, if a neutral object was touched by a charged object (e.g. negatively charged), the charging of the neutral object would take place because electrons would pass on to the neutral object. The neutral object therefore acquires a negative charge and the initially charged object becomes less negative. A limited percentage of pre-service teachers (8%) described friction and contact charging as a result of either proton or electron transfer, revealing their difficulties in understanding the structure of the atom (Figure 1).

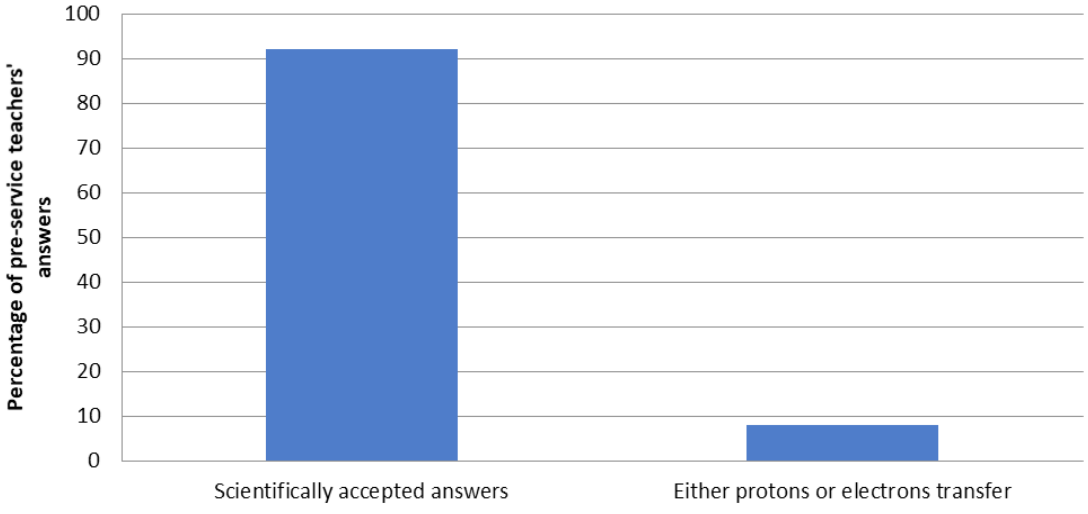

Figure 1. Pre-service teachers' views about charging by friction and contact.

Table 1 provides examples of answers coded as scientifically accepted and non-accepted.

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Table 1. Examples of pre-service teachers' views about charging by friction and contact.

Thematic category	Scientifically accepted answers	Non-accepted answers
Charging by friction	During friction, electrons that are looser (e.g. the electrons of one object) are transferred to the other object. As a result, the one object is positively charged and the other is negatively charged. We do not know "which is which" for every pair, but it depends on electrons!	The friction causes the transfer of either electrons or protons from one object to the other.
Charging by contact	The negatively charged object gives some of its electrons to the electroscope. That's why it opens. If the rod is positively charged, then the electrons pass from the electroscope to the rod. As a result, the plates of the electroscope are positively charged, and they repel each other.	The glass rod gives its positive charge to electroscope and it causes the plates to open.

Figure 2 presents the pre-service teachers' views on the distinction between conductors and insulators (1st Experiment: Figures 5 & 7). Most of them gave precise explanations regarding the fact that the far end of the glass rod (Figure 5) was not electrified, since glass is an insulator and electrons cannot move from one side of the material to the other. Most participants explained that the charge caused by friction remains in its original position. A limited percentage of them (18%) gave a different explanation: namely, that the leaves of the electroscope do not open because no charge remains, in the sense that all the charge was consumed during the previous experiment (Figure 4). Regarding touching the other side of the metallic cylinder, the one with the sticker (Figure 7), most participants could explain why the electroscope's leaves open, describing the free movement of electrons within the metal. Most of them attributed this property to the fact that the cylinder is a metal. A limited percentage (10%) had to deal with a failed experiment, probably due to the cylinder having discharged through their hand. Unaware of what had gone wrong, these students came up with explanations such as the cylinder has no more charge to pass on to the electroscope. Although such an explanation was very close to the explanation pertinent to the glass rod, it originated from a different place.

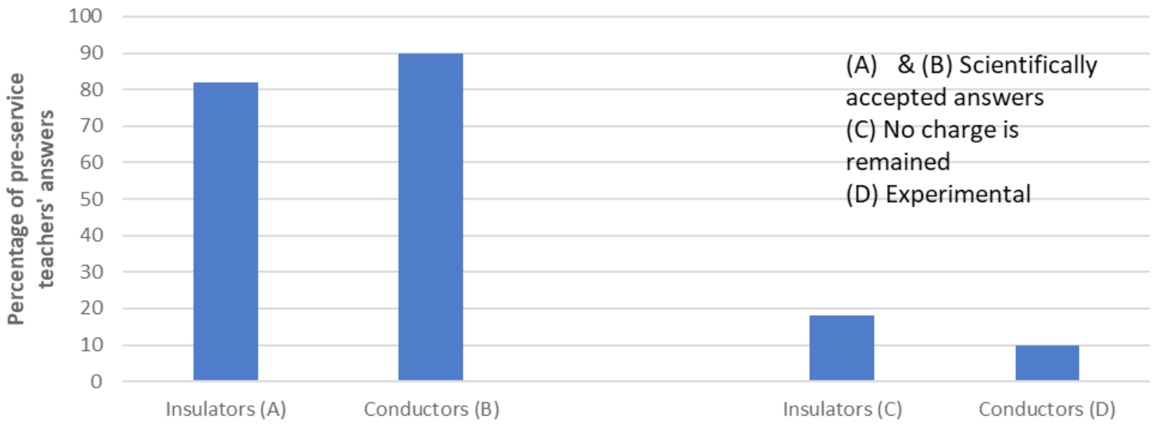

Figure 2. Pre-service teachers' views about conductors and insulators.

Table 2 provides examples of pre-service teachers' views about insulators and conductors.

Regarding charging conductors by induction, 73% of the pre-service teachers gave complete explanations. A remarkably high percentage of them had difficulties explaining why the electroscope opened when the charged glass rod was brought near it (2nd Experiment: Figure 8). Specifically, 27% of the participants believed that the electric charge of the glass rod was transferred through the air to the metal disc (Figure 3) and that the metal disc, as a conductor, then allowed the electric charge to move to the plates of the electroscope, thus charging them with the same electric charge. Which is to say that the pre-service teachers did not attribute the charging of the electroscope plates to the movement of the electrons inside the electroscope, but rather to a charge resulting from an electric charge transfer from the rod to the metal disc. They said that, even from a distance, the rod would transfer its charge to the metal disc of the electroscope.

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Regarding charging insulators by induction (dielectric polarization), only 12% successfully described the natural procedure under discussion. The majority of pre-service teachers (88%) were unable to explain the mechanism whereby the molecules in the styrofoam are polarized due to the glass rod's static electricity. Specifically, they explained the attraction between the rod and the styrofoam pendulum (Figure 3) as:

Table 2. **Examples of pre-service teachers' views about conductors and insulators.**

Thematic category	Scientifically accepted answers	Non-accepted answers
Insulators	The second end of the glass rod has no charge because electrons cannot move into the insulators.	The second end of the glass rod has no charge left. It was all consumed during the previous experiment.
Conductors	The other side of the metallic cylinder is charged because electrons can move freely in conductors. That's why the electroscope open.	Cylinder's charge has finished due to its previous contact with the electroscope.

a) Attraction between a charged and a neutral object. 42% of the pre-service teachers reported that the charged glass rod attracts the styrofoam ball, which is electrically neutral, implying that there is not necessarily a need for two charged objects. They did not make any reference to polarization, meaning the displacement of electrons within the same molecule, which is to say they used an explanatory framework according to which electric force can be transferred between electrified and non-electrified bodies. They did not explain how the pendulum's neutral ball acquires electrostatic properties.
b) Attraction between oppositely charged objects. 17% of the pre-service teachers claimed the attraction between the rod and the styrofoam ball was due to the two objects being oppositely charged but failed to explain how the ball came to be oppositely electrified.
c) Attraction between oppositely charged objects resulting from electron transfer from one object to another. 14% of the pre-service teachers claimed that the charged glass rod provides electrons to the styrofoam ball at a distance, meaning the electric charge "leaped" through the air from the rod to the styrofoam ball. This electron transfer results in the rod losing all its electrons ending up positively charged, while the styrofoam pendulum is negatively charged. In this case, students used an alternative explanatory framework based on the "construction" of two oppositely charged bodies: the positive rod and the negative styrofoam ball.
d) A result of the glass rod's contact with the styrofoam pendulum. 15% of the pre-service teachers considered the attraction to be caused by the contact between the charged rod and the pendulum ball. They argued that the electrically charged rod gave electrons to the pendulum ball during the contact between the two bodies, leaving the ball negatively and the rod positively charged. They therefore explained the attraction between the styrofoam ball and the glass rod as resulting from the ball being loaded with an electric charge opposite to the charge on the rod. These pre-service teachers did not realize that the two objects attract each other at a distance, meaning they are repelled if they touch each other.

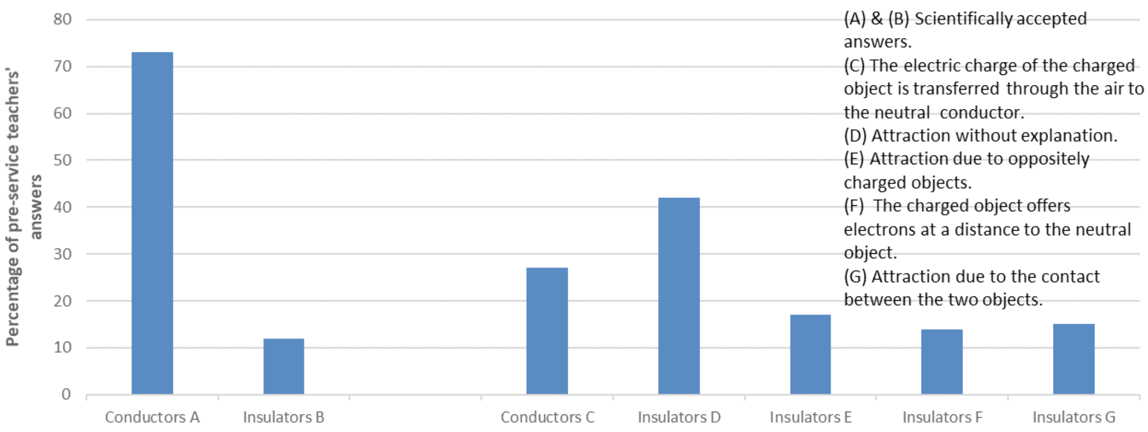

Figure 3. **Pre-service teachers' views about electrostatic induction- polarization.**

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Table 3 provides examples of pre-service teachers' answers on charging by induction which have been coded as accepted or non-accepted. Scientifically non-accepted answers have been classified according to their content (C, D, E, F, G) and are depicted in Figure 3.

To determine whether there was a statistically significant difference between the percentages of pre-service teachers who answered correctly and incorrectly respectively, a one-sample t-test was conducted. Analysing the answers concerning friction and contact electricity revealed that there was a significant difference between the scores of those who gave scientifically accepted answer (92%) and those who did not (8%) ($t(199) = 21.894$, $p < .001$). These results (Table 4) suggest that most pre-service teachers are able to give scientifically accepted explanations about friction and contact electricity.

Testing the difference between conductors and insulators it was concluded that although most pre-service teachers hold scientifically accepted views about the difference between conductors and insulators, there is a statistically significant percentage of them that had difficuties understanding the different roles electrons play in conductors and insulators. Examing the pre-service teachers answers on charging by induction, it was found that a statistically significant percentage of them attributed charging by induction to electron transfer through the air from the metallic cylinder to the electroscope (Table 4).

In the case of charging by dielectric polarization (Table 5) a comparison between scientifically accepted answers and those from different categories was conducted. A statistical difference was found ($t(199) = 6.325$, $p < .001$) between pre-service teachers who gave accepted answers (12%) and those who could not provide a solid explanation (42%). These findings suggest that most of the pre-service teachers felt uncomfortable explaining dielectric polarization. Such a hypothesis is supported by the comparison of the three categories of difficulties faced by the remaining (46%) pre-service teachers; attraction between oppositely charged objects (17%), electron transfer through the air (14%), and attraction as a result of contact charging (15%).

However, there was no significant difference between those who gave accepted answers (12%) and those who attributed dielectric polarization to oppositely charged objects (17%). Similarly, no significant difference was found when the percentage of accepted answers were compared to the answers attributing polarization to electron transfer through the air (Table 5). Finally, there was no significant difference between the percentage of accepted answers and answers attributing polarization to attraction as a result of contact charging; ($t(199) = 0.818$, $p = .41$). Although some differences were not statistically significant, the results provided strong evidence that pre-service teachers faced difficulties explaining static electricity, and especially induction and dielectric polarization.

Table 3. Examples of pre-service teachers' views about charging by induction.

Pre-service teachers' answers	Insulators	Conductors
Scientifically accepted answers	The styrofoam electrons cannot move freely as they do in conductors. When the "let's say" positive charged rod is brought close to the styrofoam ball, the atoms in the styrofoam are oriented as though the electrons are trying to approach the positive object.	When the supposedly positive charged glass rod is brought near the electroscope, it attracts the electrons in the metal. The plates are positively charged, and they open.
Attraction without explanation (Non- accepted answers)	The glass rod is charged, and that is why it attracts the ball.	-
Attraction between oppositely charged objects (Non-accepted answers)	The rod and the ball are oppositely charged. They attract each other!	-
Electrons' transfer through the air (Non-accepted answers)	Electrons pass through the air from the rod to the ball. That's why the two objects end up with opposite charges. They attract one another.	Electrons pass through the air from the rod to the electroscope or vice versa. As a result, the one object is positive and the other negative. They attract one another!
Attraction as a result of contact charging (Non-accepted answers)	The rod and the ball come into contact with one another. They are subsequently oppositely charged and attract one another.	-

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Table 4. Statistical presentation of pre-service teachers' answers concerning charging by friction, contact and induction.

Pre-service teachers' answers	Scientifically accepted (%)	Non-accepted (%)	One-sample t-test
Friction and contact electricity	92	8	$t(199) = 21.894$, $p < .001$
Insulators	82	18	$t(199) = 11.779$, $p < .001$
Conductors	90	10	$t(199) = 18.856$, $p < .001$
Induction	73	27	$t(199) = 7.327$, $p < .001$

Table 5. Statistical presentation of pre-service teachers' answers concerning dielectric polarization

Scientifically accepted answers (%)		12
Non-accepted answers (%)		**One-sample t-test**
Attraction without explanation	42	$t(199) = 6.325$, $p < .001$
Attraction between oppositely charged objects	17	$t(199) = 1.319$, $p = .19$
Electrons' transfer through the air	14	$t(199) = 0.555$, $p = .58$
Attraction as a result of contact charging	15	$t(199) = 0.818$, $p = .41$

Table 6. Statistical test for comparison gender.

Pre-service teachers' answers	Scientifically accepted (%) Female	Scientifically accepted (%) Male	Two-sample t-test
Friction and contact electricity	91	97	$t(198) = 1.111$, $p < .268$
Insulators	82	83	$t(198) = 0.132$, $p < .895$
Conductors	89	97	$t(198) = 1.359$, $p < .176$
Induction	72	80	$t(198) = 0.912$, $p < .363$
Polarization	12	13	$t(198) = 0.155$, $p < .877$

To determine whether there was a statistically significant difference based on gender, a two-sample t-test was conducted. The results (Table 6) suggested that there is no statistically significant difference between the answers of the male and female participants.

Discussion

This research sought to identify the extent to which pre-service primary teachers are able to construct scientifically accepted views on the processes involved in static electricity after an IPLC, and to address any weaknesses identified. The participants answered an open-ended questionnaire consisting of six questions focusing on the three types of charging.

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The research, which was based on the content analysis of pre-service teachers' written reports, demonstrated that the majority of participants could give scientifically accepted explanations for friction and contact electrification. Their conceptual difficulties primarily related to induction and polarization procedures.

Regarding friction and contact electrification, the majority of pre-service teachers could explain the corresponding microscopic processes and correctly attribute charging to electron transfer. This result is in line with the literature, which has highlighted that students understand electrification as a process that takes place solely through friction (Calilot & Xuan, 1993; Siegel & Lee, 2001). Nevertheless, the results reveal that a limited percentage of pre-service teachers faced difficulties explaining friction and contact electrification, wrongly viewing either proton or electron transfer from one object to another as the cause of the charging. These pre-service teachers seemed to find it difficult to associate contact and friction electrification with atomic structure. These findings accorded with the research results reported in the literature (Sarikaya, 2007). If a proton transfer had occurred between the rubbed objects, or the objects had simply come into contact with one another, then there would have been a transfer from one nucleus to another, since protons cannot exist as independent particles in matter. This specific conceptual difficulty implies a change in atomic number, meaning a change of identity. Such thinking is as far from reality as the idea espoused by alchemists that gold could be made from copper. In fact, the pre-service teachers knew that a new atom is not produced by rubbing or from coming into contact with another "atom". They could see that the glass rod, the metallic cylinder and wooden cloth did not change during the experiments. This would indicate that pre-service teachers are unable to link their knowledge of atoms to the explanation of friction and contact electricity.

The findings of this research showed that pre-service teachers' difficulties relate primarily to the induction/polarization processes. Specifically, they seem to relate to the fact that pre-service teachers do not perceive electrostatic induction as a process of free electrons moving from one portion of an object to another due to another charged object (induction in conductors), or as a process of electron redistribution within the atom or molecules nearest the outer surface of the object (polarization in insulators).

Most pre-service teachers appeared embarrassed when they were asked to explain charging by induction, in the sense that they could not attribute electrostatic properties to a neutral object like the styrofoam ball. A similar situation was reported in the literature, with unskilled workers, staff employees (Calilot & Xuan, 1993) and engineering students (Thacker et al, 1999) finding it hard to understand that a neutral object can carry a charge and therefore interpreting the electrostatic attraction between a charged and a neutral object as electrons jumping through the air from one object to another. This same idea - that charge can leap from one plate to another - was also mentioned in research conducted regarding the capacitors with tenth-grade students (Başer & Geban, 2007). This seems to be related to a poor understanding of the structure of conductors and insulators and the role free electrons play in them, which could explain the reason why pre-service teachers sought to avoid expressing their views about the mechanisms of induction and polarization, in the sense that they did not distinguish between the role of mobile free electrons in conductors and the less mobile atom-bound electrons in insulators.

These findings are more meaningful, especially if we consider that the participants in this study had experience of being taught atomic theory, electrostatics, conductors, insulators, etc. at school. This can be taken as evidence that focusing primarily on macroscopic phenomena, contributes little to the students' understanding of the corresponding microscopic procedures. This is also the conclusion presented in the related literature (Guisasola, 2014) which proposes starting the electricity curriculum with elementary electric phenomena (electrification by friction, contact and induction) and focusing students' attention on the microscopic explanatory models to improve their understanding.

It is well documented (Calilot & Xuan, 1993; Eylon & Ganiel, 1990; Galili, 1993; Guruswamy et al., 1997; Hermita et al., 2017; Siegel & Lee, 2001; Thacker et al., 1999) that high school and university students as well as adults have great difficulty understanding and explaining static electricity procedures and phenomena. Such difficulties have been revealed by research conducted on DC electric circuits, electric shocks, electric fields and other electrostatic topics in which - unlike other areas of Physics, such as mechanics, where processes can be visualized directly - everything observed is an indirect manifestation of some hidden microscopic process.

The most important contribution of this research is that it identified conceptual difficulties concerning static electricity, with a focus on the three types of electrification. Such an approach revealed that pre-service teachers' difficulties were associated with their difficulties in linking up atomic structure to static electricity phenomena.

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Such findings are important due to the singularity of the sample; pre-service primary teachers have to teach science in primary education, so it is crucial to address their understanding and identify any confusion, at the microscopic level, especially, in order to propose ways to overcome them.

The findings of this research provide evidence that pre-service teachers have difficulty achieving a robust understanding both of the microscopic procedures involved in induction, dielectric polarization and of the differences between conductors and insulators. According to the results, these difficulties related to the different roles electrons play in insulators and conductors. The research would thus indicate that a deeper analysis of the microscopic procedures involved in electrostatics is needed. Based on the findings of the present study, further research could provide evidence for pre-service teachers' views on the role of conductors and insulators in electrostatics and electromagnetic phenomena in general.

What is highly recommended is building macro-micro relationships based on electrostatic experiments supported by theories and models of static electricity generation mechanisms. It is recommended that microscopic models are included in the electricity curriculum in schools and universities, since they help students develop their understanding of the relationship between macroscopic phenomena and microscopic-level models. In addition, inquiry-based teaching is recommended, in which pre-service teachers can actively engage in developing scientifically accepted explanations. Students will not only conduct the experiments, they will also learn how to test their hypotheses and build their own models that attempt to explain static electricity phenomena. By comparing their models with exemplary software (e.g. Phet Colorado) they could gradually develop scientific explanations.

Conclusions

This research served two objectives: (1) to examine the extent to which pre-service primary teachers are able to construct scientific explanations relating to static electricity, and (2) to identify the conceptual difficulties pre-service teachers encounter when they have to explain the basic phenomena of static electricity: friction and contact electricity and charging by induction. After pre-service teachers had completed the IPLC, they delivered a written report in which they had to express their views on three types of charging by answering six open-ended questions.

The results reveal that pre-service teachers face difficulties conceptualizing the microscopic procedures that take place during electrification. Although their difficulties primarily relate to charging by induction and dielectric polarization, the research revealed that they also face some difficulties relating to friction and contact electrification. At the core of such difficulties lies a lack of understanding of atomic structure, and hence of the microscopic procedures that take place during induction. Specifically, the pre-service teachers' answers revealed a weak understanding of the role the electrons play in each of the three types of electrification, as well as embarrassment when they had to explain the difference between conductors and insulators regarding the role of electrons in them.

Therefore, the most crucial contribution of this research is that, although findings are limited to the sample, they gave strong evidence regarding pre-service primary teachers' difficulties with all three types of electrification, implying that all these conceptual difficulties originate from a poor understanding of atomic structure and a weak association between their knowledge of atomic structure and electrification. As this research shows, pre-service teachers still have profound difficulty explaining microscopic procedures relating to static electricity phenomena, even though these phenomena are included in science curricula at every educational level from primary to tertiary education. As such, it is important that pre-service teachers' knowledge be enhanced as this will help them become adequate teachers; by helping them improve their knowledge, we may also improve their future students' understanding.

Consequently, to overcome the difficulties presented here, some alternatives and future considerations are proposed, such as the use of inquiry-based teaching in which microscopic models are integrated into the macroscopic procedures and experiments. Further research in the field could shed light on the development of teaching-learning sequences which take the relevant microscopic procedures into account in the area of electricity and beyond, e.g. thermodynamics.

Regarding the research findings, they are limited to the sample. Therefore, research on conceptual difficulties relating to static electricity and the role of electrons could be repeated to enhance the reliability of the findings.

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Appendix I

Teaching-Learning Sequence – The Experiments

The lab exercise under consideration in the present research was about static electricity and included three experiments:

*1st Experiment: Charging by friction and contact (insulators and conductors)***.** The arrangement includes a glass rod, a metallic cylinder, an electroscope and a piece of woolen cloth.

1a) Students are asked to rub one end of the glass rod (the insulator) vigorously with the woolen cloth and touch the metal disc of the electroscope with the charged end of the rod.

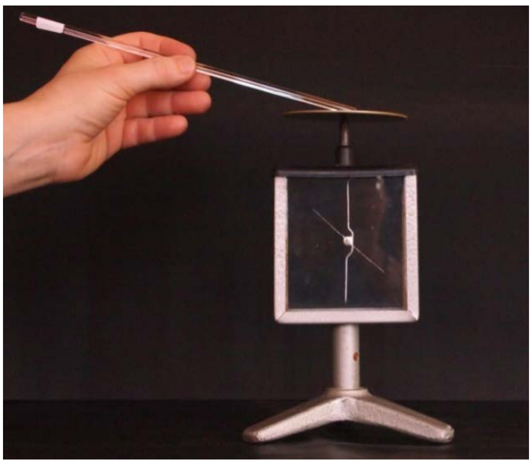

Figure 4. The electrified end of the rod causes the plates to open.

1b) After discharging the electroscope, the participants are asked to touch the metal disc of the electroscope with the other end of the rod (the one that has not been rubbed).

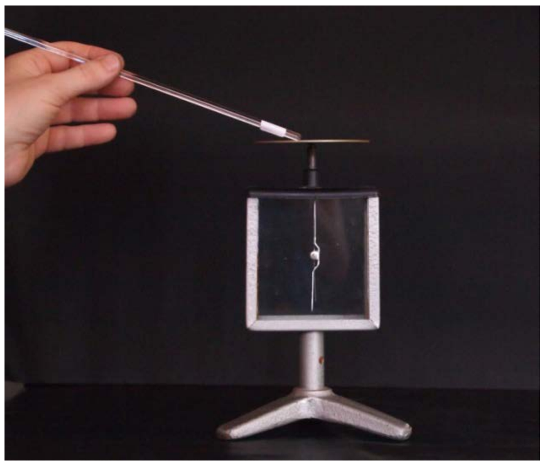

Figure 5. The other end of the rod (non-electrified) does not cause the plates to open.

1c) The students are asked to rub the metallic cylinder with the woolen cloth and then touch the metal disc of the electroscope with it.

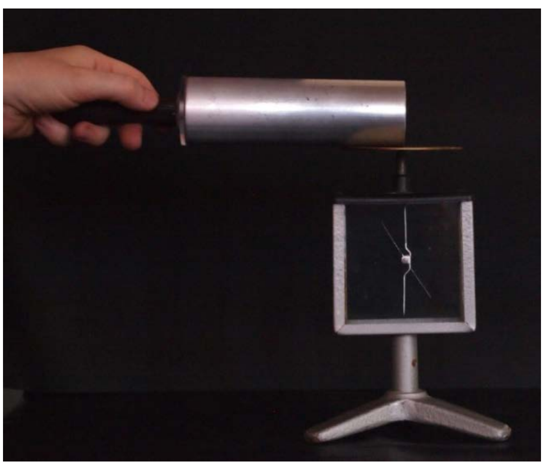

Figure 6. The electrified side of the cylinder causes the plates to open.

1d) After discharging the electroscope, the students were asked to touch its metal disc with the other side of the cylinder.

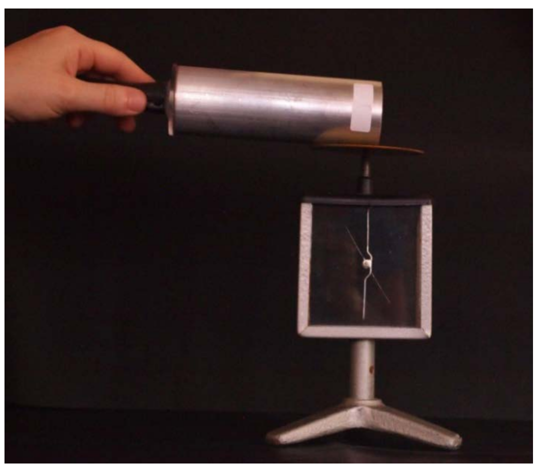

Figure 7. The other side of the cylinder (also electrified) causes the plates to open.

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2nd Experiment: Charging by induction. The arrangement includes a styrofoam pendulum, a glass rod and an electroscope.

2a) Students were asked to charge by friction the glass rod (insulator) and bring it closer to the metal disc of the electroscope (conductor).

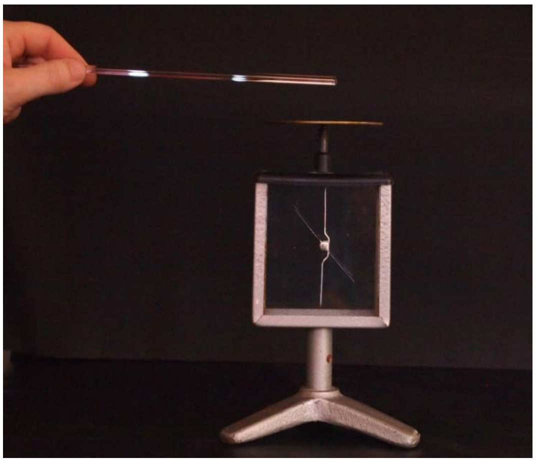

Figure 8. The metal disc and the plates of the electroscope (conductors) are charged by induction – they open when the glass rod is brought close to the metal disc.

2b) Students were asked to rub the glass rod (insulator) vigorously with the woolen cloth and bring it closer to the styrofoam pendulum (insulator).

Figure 9. The styrofoam ball (insulator) is polarized by the electrified glass rod (insulator) – the rod attracts the pendulum.

For every task, students were encouraged to keep handouts and complete worksheets, discuss and give possible explanations, documenting their work in a lab notebook. The experiments were confirmatory, which means that students have studied the theory before conducting the laboratory exercise. Regarding the role of instructor-student interaction, instructors provided support and guidance to students and summarized, generalized and synthesized when needed.

Appendix II

The following questions are part of students' written report that had as a deliverable in order to successfully complete the Introductory Physics Laboratory Course. These are the questions that most students had difficulties in answering.

1nd Experiment: Charging by friction and contact (insulators and conductors).

1. **Rub the glass rod with the woolen cloth. Then touch the metal disc of the electroscope with the end of the rod you rubbed** *(Figure 4)*.
   What do you notice?
   Can you explain the phenomenon?

2. **Discharge the electroscope by touching the metal disc with your hand. Now touch the metal disc of the electroscope with the other end of the charged glass rod (the one that was not rubbed)** *(Figure 5)*.
   What do you notice?
   Can you explain the phenomenon?

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3. **Rub the metallic cylinder with the woolen cloth. Then touch the metal disc of the electroscope with the side of the cylinder you rubbed** *(Figure 6).*
   What do you notice?
   Can you explain the phenomenon?

4. **Discharge the electroscope by touching the metal disc with your hand. Touch the metal disc of the electroscope with the other side of the charged metallic cylinder (the one that was not rubbed)** *(Figure 7).*
   What do you notice?
   Can you explain the phenomenon?

2rd Experiment: Charging by induction.

1. **(Electrostatic induction of conductors) Electrify by friction the glass rod and bring it close to the metal disc of the electroscope (do not touch it)** *(Figure 8).*
   What do you notice?
   Can you explain the phenomenon?

2. **(Electrostatic induction of insulators - Polarization) Rub a glass rod with the woolen cloth. Bring the rod close to the styrofoam pendulum. How does the glass rod interact with the styrofoam pendulum?** *(Figure 9).*
   Before rubbing it with the woolen cloth?
   After rubbing it with the woolen cloth?
   Can you explain the phenomenon?

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Constantina G. Stefanidou	Laboratory Teaching Staff, Faculty Member, Dr, Department of Primary Education, National and Kapodistrian University of Athens, Greece. E-mail: sconstant@primedu.uoa.gr Website: https://uoa.academia.edu/ConstantinaStefanidou
Konstantina D. Tsalapati	PhD Student, Department of Primary Education, National and Kapodistrian University of Athens, Greece. E-mail: kwsini@primedu.uoa.gr Website: https://www.researchgate.net/profile/Konstantina_Tsalapati
Anastasia M. Ferentinou	PhD Student, Department of Special Education, University of Thessaly, Volos, Greece. E-mail: aferentinou@uth.gr, ferentinou.a@gmail.com Website: https://uth.academia.edu/AnastasiaFerentinou
Constantine D. Skordoulis	Professor of Epistemology and Didactical Methodology of Physics, Department of Primary Education, National and KapodistrianUniversity of Athens, Greece. E-mail: kostas4skordoulis@gmail.com Website:https://www.researchgate.net/profile/Constantine_Skordoulis

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