



Article

How Elementary Pre-Service Teachers Use Scientific Knowledge to Justify Their Reasoning about the Electrification Phenomena by Friction

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Abstract: This article uses a qualitative research method to identify eighty elementary pre-service teachers' conceptual representations concerning static electricity. We carry out this analysis using a paper and pencil questionnaire. This study shows that pre-service teachers have an erroneous understanding compared to those commonly accepted by the scientific community. The inaccurate representations identified are relevant for developing teaching strategies focused on conceptual conflict.

Keywords: scientific knowledge; pre-service teachers knowledge; electrostatic; qualitative research



Citation: Métioui, A. How Elementary Pre-Service Teachers Use Scientific Knowledge to Justify Their Reasoning about the Electrification Phenomena by Friction. *Knowledge* **2022**, *2*, 103–115. <https://doi.org/10.3390/knowledge2010006>

Academic Editor: Jose María Merigo

Received: 3 January 2022

Accepted: 23 February 2022

Published: 25 February 2022

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1. Introduction

Worldwide elementary and secondary schools' curricula prescribed the study of electrical circuits and static electricity. A review of research on students' alternative conceptions and their teachers revealed less research about electrostatic phenomena [1–6] than those related to the electric circuit [7–13], despite the critical transition between these two areas of knowledge. On this subject, Bensghir and Closset [14], Métioui et al. [15], and Eylon and Ganiel [16] showed several conceptual difficulties in the study of electrical circuits result from misunderstanding electrostatic concept as electric charge. In this regard, Eylon and Ganiel [16] (p. 76) point out the following about the conceptual difficulties encountered by students about the electrical circuit.

We find that even in very simple situations, most students do not tie concepts from electrostatics into their description of the phenomena. This leads to severe inconsistencies in student answers to questions about currents, charges, and their sources in an electric circuit. Formal definitions (even when quoted correctly) are not utilized operationally. Consequently, a consistent picture of the mechanisms is usually lacking. This may explain why students cannot conceptualize the electric circuit as a system and appreciate the functional relationships between its parts (p. 76).

Furthermore, students have difficulty interpreting the sign terminals of a battery + and – and the electric current flow in a simple electrical circuit [11]. Likewise, for many students, if we touch one end of the battery terminals with the finger, we receive an electric shock [11]. In addition, many students think that a battery contains electrical charges as a water reservoir [17].

The following misconceptions are the consequence of the imprecise transition between dynamic electricity and static electricity as highlighted by many researchers [14–17]: the voltage is related to the amount of current, the current creates the voltage rather than the voltage being needed for the current to flow, the voltage could not exist if no current is flowing, batteries become flat when all of the electricity stored in the battery is used up, the “negative current” goes back to the battery and the “positive current” comes from the battery.

Interestingly, these misconceptions are also the consequence of the imprecise use of everyday language (e.g., the terms current, voltage, and electrical power are used interchangeably, voltage is the force of the electric current) [18].

This qualitative research falls within this perspective and aims to identify the scientific knowledge used by eighty elementary pre-service teachers to justify their reasoning about the electrification phenomena by rubbing, contact, and induction (polarization) as well as the formation of lightning.

2. Methodology

We gave them a paper-and-pencil questionnaire lasting sixty minutes to highlight their conceptual representations. The (open) questions were related to situations with which they interact in their daily environment, and the questions' answers require an understanding of the production phenomenon of electric charges and their displacement and the law of charges between contrary charges' objects. We have also considered the concepts prescribed in the Québec Education Program [19], where teachers are required to teach activities describing: the effect of electrostatic attraction (e.g., describes the effect of electrostatic attraction (paper attracted by a charged object), electrical conductors, and insulators, and the insulating properties of various substances).

3. Population

Within the framework of a university course on science didactics offered to students in primary school teacher training, we administered the questionnaire to eighty (80) students at the start of the course, including the average age of 23 years old. After six years of elementary school, they completed their high school diploma (five years) and their college diploma (two years) in the humanities. In high school, they took two science courses related to physics, chemistry, and the environment, and we asked them if they had ever taken a course in electrostatics. Thus, only 25% indicated studying it and vaguely remembered the concepts studied. Before they filled in the questionnaire, it was explained to them that the questions aimed to know their previous knowledge on phenomena related to static electricity that they will have to teach their future students under the training program of the Ministry of Education. We explained to them that they had to answer without worrying about the scientific veracity of their explanations and that they would have the opportunity to compare them to those that will be studying during the course on this topic.

4. Construction of the Questionnaire

We constructed six questions and the students had to rely on their scientific knowledge (i.e., their explanatory model) to answer them. The questionnaire could not be answered adequately by referring to the notion learned "mechanically" by rote. Table 1 presents the formulated questions and their answer scientifically accepted. To ensure the scientific validity of our answers, we consulted scientific literature [20–22]. Note that the responses conform to the electrification by friction and the polarization phenomenon as developed in the context of static electricity associated with the study of electrical charges at rest.

Furthermore, we validated the questionnaire with three university professors in science education who noted that the wording of the questions was understandable for elementary pre-service teachers who are not scientists and that the answers to the questions do not require any quantitative reasoning. Therefore, answers were clearly formulated, even if the concepts raised, such as the electric field, were not explored in depth. Note that the questions selected are related to the students' environment. They also cover the phenomenon of electrification by friction, the law of charges between rubbed objects, and matter polarization.

Table 1. Paper and pencil questionnaire and answers.

Question 1	Why, sometimes, does hair stand on end after combing it? Explain your answer as well as you can.
Scientific knowledge	
It is a phenomenon of electrification by friction and repulsion between charges of the same signs (positive/positive or negative/negative). The hairs were charging because of their friction with the comb (e.g., the comb became positively charging (electrons loss) and hairs negatively (electrons gain) because of their friction. Following the law of electric charges, hairs stand on end because their charge has the same sign.	
Question 2	Why does the “anti-static” paper (fabric softener) in a dryer reduce static build-up? Explain your answer as well as you can.
Scientific knowledge:	
In the machine dryer, the pieces of laundry are charged positively and negatively due to their friction. We interposed between the laundry anti-static paper to reduce the transfer charge from one laundry to another. The paper acts as a “sponge” by “absorbing” negative charges, a kind of capacitor. Furthermore, one can make the analogy between the paper in the dryer and the water vapor (humidity), which reduces the formation of static electricity in each place.	
Question 3	Why, sometimes, does a balloon rubbed on hair stick on a wall? Explain your answer as well as you can.
Scientific knowledge:	
The balloon charged, for example, negatively due to its friction on the hair created an electric field that induces polarization in the wall. The opposite charges to those of the balloon closest to it explain the attraction of the sticky balloon.	
Question 4	Why does a plastic ruler previously rubbed with wool attract some small pieces of paper without touching them? Explain your answer as well as you can.
Scientific knowledge:	
The scientific explanation of this phenomenon involves the polarization properties of dielectric material as illustrated to question 3. So, the plastic ruler was charging (e.g., negatively) due to its rubbing against the woolen fabric that loses negative charges (electrons); it creates an electric field that induces a polarization in the paper by creating “dummy” polarization charges. The opposite charges to the ruler closest to it are responsible for the attraction. Note, we observed pieces of paper attraction from a distance because of their lightness, which is not the case with the wall.	
Question 5	How does lightning form during a thunderstorm? Explain your answer as well as you can.
Scientific knowledge:	
The phenomenon of lightning forming during a thunderstorm is complex and can be explained in three stages: 1. The friction between the water droplets and the hailstones in the cloud gives rise to a separation of charges in the cloud (e.g., its lower part having a charge of opposite sign to its upper part); 2. When the cloud is near the ground, its negatively charged polarizes atoms in the ground and creates a positively charged surface; and 3. When this concentration of charges is intense, the air becomes ionized, making it conductive; then, an attraction between the negative and positive charges becomes sufficient to allow the charges to cross the gap between the cloud and the ground, creating an emission of light (photons) that we designate by the word lightning.	
Question 6	How to explain that by rubbing our feet on a carpet in dry weather, we can catch a shock by touching a metal doorknob or another person?
Scientific knowledge:	
Friction between the feet and the carpet causes loads to shift from the carpet to the feet, which become loaded. As the body is a conductor, loads in the feet can travel up to the hand. The negatively charged hand polarizes atoms’ handles and creates a positively charged surface. Thereby, a hand’s negative charges attract with handling positive charges at a distance. The attraction becomes strong at the shortest distance, and if it is dark, we will see a little lightning, and we receive an electric shock when we touch the door handle. The same thing happens when we sometimes give our hand to a particular person.	

5. Data Analyses

We present below the representations identified in each question following the analysis of the answers, followed by the students’ comments through illustration. The scientific knowledge synthesized in Table 1 is essential because it constitutes our analyses grid. Thereby, we construct a conceptual representation of responses having similar intended meanings. Note that the representations’ numbers depend on the question and the student’s answers.

5.1. Data Analysis: Question 1

Analysis of the responses allowed us to identify four conceptual representations to explain this phenomenon: 1. As a result of friction, the comb gives up electrons (negative charges) to the hair. These have the same charge (negative), repel each other, 2. Friction between the comb and the hair creates a transfer of static electricity (or electric charges) to the hair, hence their repulsion, 3. The hair stands on end due to the static electricity created by rubbing against the comb, and 4. Hair stands on end due to the electrical charges in the surrounding air.

Students' numbers identified for each representation, and some of their responses are presented in Table 2, followed by our analyses.

Table 2. Student scientific knowledge about hair repellency and their analyses.

Question 1: Why, sometimes, does hair stand on end after combing it?	
Representation 1 (10/80–13%): As a result of friction, the comb gives up electrons (negative charges) to the hair. These have the same charge (negative), repel each other.	
Student scientific knowledge	Analyses
<p>“The friction between brush and the hair produces the phenomenon of electrification by friction, that is to say, that the effect of friction will cause a transfer of electrons from one material to another, either between the brush and the hair. Due to this electron transfer, the hair will charge the same sign. The repulsion of charges of the same sign, so the hair will grow back and stand on end.” (E₂₈)</p> <p>“The hair stands on end because there is a transfer of loads between it and the comb. This transfer will create the presence of charges of the same signs in the hair, which will grow back from where it stands.” (E₄₅)</p> <p>“So, the hair would all become of the same load and repel each other?” (E₅₀)</p>	<p>The answers put forward as to why hair stands on end are correct. They implicitly applied the law of repulsion between charges of the same signs in the case of hair and the phenomenon of hair electrification by friction with the comb (transfer positive or negative charges from one object to another).</p>
Representation 2 (14/80–18%): Friction between the comb and the hair creates a transfer of static electricity (or electric charges) to the hair, hence their repulsion.	
<p>“They lift themselves into the air with static electricity transmitted to them.” (E₄₈)</p> <p>“It is about transferring the electrostatics from my brush into my Hair.” (E₄₉)</p> <p>“Friction between the brush and the Hair causes a transfer of static electricity from the brush to the Hair.” (E₇₀)</p> <p>“Since there is friction between the comb and the Hair, it creates a transfer of electrical charges from one object to another (comb to the Hair). Hair stands on end when combed.” (E₇₅)</p>	<p>Those students do not specify why the friction charged the hair and its meaning, and it is also not explained why the balloon sticks on the wall.</p> <p>Because of the friction, the hair and the comb become charged; that is, hair and the comb are not anymore electrical neutral.</p>
Representation 3 (26/80–32%): The hair stands on end due to the static electricity created by rubbing against the comb.	
<p>“When combed, they stand up from the static. Friction forms Statics. Statics make our hair stand up.” (E₂₀)</p> <p>“The Friction between the brush and the hair creates static. So the hair no longer stays in place on the head, but rises into the air like being rubbed against an inflatable balloon.” (E₂₅)</p> <p>“Rubbing her hair against the brush creates static electricity. This electricity is what attracts the hair to the brush, making the hair stand up when combed.” (E₅₂).</p>	<p>Incomplete explanation because they do not specify what the statics represent or the link between the friction of the hair and why it stands up.</p> <p>As stated above, electron transfer occurs when we rub one material on another, and thus, there is a modification of the two objects. It is about the phenomenon of friction electrification.</p>
Representation 4 (16/80–20%): Hair stands on end due to the electrical charges in the surrounding air.	
<p>“This phenomenon is explained by a static effect. When we comb our hair, the comb comes in contact with air which contains a lot of electrons.” (E₂₂)</p> <p>“The air must be charged with electricity, which produces the phenomenon of static electricity between the air, the brush and our hair.” (E₄₃)</p> <p>“In this case, there is an electric charge in the air which attracts the hair and makes it stand up.” (E₆₃)</p> <p>“I think it is because of the air around us. When it is colder, the hair stands on end and becomes drier.” (E₆₆)</p>	<p>Atmospheric conditions indeed affect the phenomenon of electrification by friction. For example, when the air is dry, the hair will stay repulsed longer than if the air is humid. These students have conceptual difficulties explaining the electrification of hair by friction and the atmospheric conditions that can disrupt this electrification.</p>

Other students' (14/80–17%) answers are indecipherable to regroup them in given representations. By way of illustration, here are some advanced answers:

“Because hair contains electrical charges too. Our brush or comb also contains electrical charges opposite to those of our hair. So it is like a magnet, opposing forces attract, and equal forces repel each other. It is electrostatics.” (E₁₈)

“There is an activation of neutrons and electrons that causes a magnetic charge, like a little with magnets, except that there is not necessarily the presence of ferromagnetic metals.” (E₂₃)

“When combing the hair, I create heat which agitates the atoms that compose it and creates electrostatic energy, which acts like a magnet.” (E₃₀)

5.2. Data Analysis: Question 2

This question aimed to find out how the students explain the effect of “anti-static” paper in a dryer to reduce the formation of “static” in clothes. As highlighted in Table 1, the focus of this question concerns the property of dryer sheets to reduce static formed during drying, and this phenomenon is familiar to them.

Two representations emerge from the analysis of the advanced responses:

1. The fabric softener paper prevents static formation due to its chemical composition.
2. The fabric softener prevents static formation because the paper components have the property of absorbing the static.

Students' numbers identified for each representation, and some of their responses are presented in Table 3, followed by our analyses.

Table 3. Student scientific knowledge relative to “anti-static” paper and their analyses.

Question 2: Why does the “anti-static” paper (fabric softener) in a dryer reduce static build-up?	
Representation 1 (33/80–41%): The fabric softener paper prevents static formation due to its chemical composition . . .	
Students scientific knowledge	Analyses
“It should be made of a particular material that is resistant to static.” (E ₄) “It is because of the components of the anti-static paper. There must be a chemical.” (E ₁₃) “It is because of the composition of the anti-static paper. This is probably something that will spread all over the clothes to prevent static on them.” (E ₅₃)	These explanations are incomplete. It is fair to say that fabric softener paper has a chemical composition that causes laundry to be lightly or lightly loaded. However, there is no explanation for the laundry and the fabric softener without knowing its chemical composition. Fabric softener sheets are chemically composed to reduce the number of electrons transferred from one laundry to another due to their rubbing, much like a sponge or a capacitor.
Representation 2 (29/80–36%): The fabric softener prevents static formation because the components of the paper have the property of absorbing the static.	
“Its composition made of material that attracts and absorbs the static created when we put our clothes in the dryer. So, there is none left on our clothes.” (E ₆) “Antistatic paper has a material that keeps the static in the paper.” (E ₂₀)	We underline an essential property of paper: it attracts the static (rather negative charges) created (instead, which is transferred from one laundry to another due to their friction). Laundry in the dryer becomes electrified by friction due to electron transfer, and the fabric softener sheets get between the laundry and limit the transfer of electrons.

Other students' (10/80–13%) answers are indecipherable to regroup them in given representations:

“It is that statics is a form of energy that we can remove. Indeed, it is like an electric current, if you remove the battery, there is no more current.” (E₇)

“I think this is to prevent an explosion or ignition in the dryer due to the high amount of friction? Perhaps this paper absorbs the electricity produced like a battery?” (E₁₇)

“I think the Bounty gives off a scent, which negates the static potency. Adding another derivative through the heat or introducing another material into that heat changes the current. A bit like when we wet a garment: the change in temperature moves away from the static.” (E₂₇)

Eight (10%) students have also admitted having no idea why this is so:

“As the name suggests, the paper will prevent the build-up of static electricity; however, I do not see how that works.” (E₁)

“I do not have the faintest idea.” (E₃₄)

5.3. Data Analysis: Question 3

Students asked how they explained that a balloon that had previously rubbed on hair could stick to a wall regarding the second question. The goal is to see if they refer to the polarization phenomenon (see Table 1). Five conceptual representations emerged from the data analysis: 1. The balloon sticks to the wall because statics (or static electricity) created by rubbing makes it stick to the wall; 2. Hair’s charges were transferred to the balloon because of friction is why it sticks at the wall; 3. The balloon sticks to the wall because the balloon charges negatively due to friction against the hair, and it sticks to the wall positively charged; 4. Static energy is produced by rubbing the balloon against the hair and transferring it to the wall; it is why the balloon sticks to the wall, and 5. The balloon is charged (positive or negative) because of friction against the wool. The opposite charge in the wall interacts with the balloon charges; explains how it becomes stuck on the wall.

Students’ numbers identified for each representation, and some of their responses are presented in Table 4, followed by our analyses.

Table 4. Student scientific knowledge about the balloon sticking to the wall and their analyses.

Question 3: Why, sometimes, does a balloon rubbed on hair stick on a wall?	
Representation 1 (21/80–26%): The balloon sticks to the wall because statics (or static electricity) created by rubbing makes it stick to the wall	
Student scientific knowledge	Analyse
<p>“By rubbing the balloon on the hair, you create static, and then it can stick to the wall.” (E₆₅)</p> <p>“When you rub a balloon on your hair, that balloon charges with static electricity, which allows it to stick to the wall.” (E₇₈)</p>	<p>No explanation about the static charge created (or statics) gave no more the relationship between the “static” and the balloon stuck to the wall. In this representation, the interaction hair–balloon (friction) is evoking, but the one between the ball and the wall was not. As indicated, the balloon stuck to the wall because a charged balloon creates an electric field that induces polarization in the electrically neutral wall: charges opposite to those of the balloon, which are closest to it, explain the attraction under the law of charges of contrary signs.</p>
Representation 2 (12/80–15%): Hair’s charges were transferred to the balloon because of friction is why it sticks at the wall.	
<p>“Charges were transferring from the hair to the balloon. This makes the balloon stick to the wall.” (E₇₅)</p>	<p>Effectively, the balloon charges due to the transfer of charges. On the other hand, no explanation is underlining concerning the interaction between the charged balloon and the wall (electrically neutral) or what is meant by charge transfer. The balloon polarizes in the presence of the charged balloon, which is why it sticks to the wall. Furthermore, the ball will charge negatively (gain of electrons) or positively (loss of electrons) and vice versa for the hair.</p>
Representation 3 (16/80–20%): The balloon sticks to the wall because the balloon charges negatively due to friction against the hair, and it sticks to the wall positively charged.	
<p>“The balloon becomes negatively charged, so it sticks to the wall positively charged to it.” (E₅₀)</p> <p>“The hair has a positive charge which it transfers to the balloon, and the wall charges negatively, so the two attract each other.” (E₆₇)</p>	<p>The hair has positive and negative charges in equal numbers before being rubbed against the wool. As a result of friction, some of their negative charges were transferred to the balloon, which become positively charged. The balloon becomes negatively charged (electron gain), and the wall contains positive and negative charges. The positive wall charges attract the negative balloon charges, and the negative wall charges move further away due to the negative charges of the balloon according to the law of charges.</p>

Table 4. *Cont.*

Representation 4 (15/80–19%): Static energy is produced by rubbing the balloon against the hair and transferring it to the wall; it is why the balloon sticks to the wall.	
<p>“The static energy created by the friction causes the party balloon to stick to the wall. Electrons and protons must move because of friction.” (E₅)</p> <p>“When you rub them together, it creates static energy, and that energy then goes to the wall, which is why we get to stick the ball there.” (E₁₄)</p>	<p>Protons do not move due to friction; it is electrons that move (E₅). The object that loses electrons and, by definition, is positively charged. As for electrostatic energy is not transmitted to the wall (E₁₄). Electrostatic energy represents the work to transport a charge (for example, there is a transport of charges in a capacitor between the armature).</p>
Representation 5 (16/80–20%): The balloon is charged (positive or negative) because of friction against the wool. The opposite charge in the wall interacts with the balloon charges; explains how it becomes stuck on the wall.	
<p>“The balloon is charged negatively, the wall being neutral, the negative charges of the wall were repelling, and therefore the positive charges of the wall attract the negative charges of the balloon.” (E₁₃)</p> <p>“When the balloon rubbed on the head, it will receive or lose charges (transfer of charges from the head to the ball or vice versa). The opposing charges on the wall will attract the ball.” (E₄₅)</p> <p>“These are the positive ions that will then attract elements of the opposite charge to them or, on the contrary, repel elements of the same charge.” (E₆₅)</p>	<p>Only one student implicitly referred to the attraction between charge and electrical neutral objects (E₁₃).</p> <p>E₄₅ and E₆₅ implicitly refer to the law of attraction or repulsion between charged objects according to their charges. Thus, one does not specify that the wall is electrically neutral.</p>

5.4. Data Analysis: Question 4

Students were asked how they explained that a plastic ruler that had previously been rubbed on a piece of woolen cloth attracts small pieces of paper at a distance regarding the third question. The goal is to see if they refer to the polarization phenomenon illustrated above (Table 1). Note that this question is related to the same phenomenon studied in the preceding question. Four conceptual representations emerged from the data analysis: 1. When approaching the charged ruler (e.g., negatively charged) of the pieces of paper (electrically neutral), the positive charges of the pieces of paper are closest to the ruler, which explains the observed attraction; 2. The friction of the ruler creates an electric field that attracts the pieces of paper from a distance; 3. The static energy in the ruler acquired due to its friction is transmitted to small pieces of paper and attracts them; and 4. The friction of the ruler creates a magnetic field that attracts the pieces of paper from a distance. Students’ numbers identified for each representation, and some of their responses are presented in Table 5, followed by our analyses.

Table 5. Student scientific knowledge about the piece of paper attraction and their analyses.

Question 4: Why does a plastic ruler previously rubbed with wool attract some small pieces of paper without touching them?	Representation 1 (5/80–6%): When approaching the charged ruler (e.g., negatively charged) of the pieces of paper (electrically neutral), the positive charges of the pieces of paper are closest to the ruler, which explains the observed attraction.
Student scientific knowledge	Analyse
<p>“The rubbing of the plastic ruler on the fabric has caused electrons to transfer from the material to the plastic ruler because plastic tends to attract electrons more than cloth. As a result, the rule became negatively charged. Then the negatively charged ruler placed near the paper ends will attract the ends because the charges positive and negative attract. It is called the phenomenon of electrification by induction. A neutral object (pieces of paper) near a negatively or positively charged object (plastic ruler) generates the reorganization of the charges in the neutral object. The faces of the pieces of paper exposed to the negatively charged rule will accumulate the negative charges transmitted to them by the plastic mater.” (E₂₈)</p>	<p>The present explanation is appropriate. The student refers adequately to the polarization phenomenon to justify the loaded ruler’s attraction of pieces of paper as synthesized in Table 1.</p>
<p>Representation 2 (12/80–15%): The friction of the ruler creates an electric field that attracts the pieces of paper from a distance</p> <p>“The ruler emit an electrostatic field which attracts objects capable of reacting to this force, much like the magnetic field of a magnet.” (E₆)</p> <p>“The friction caused an electrostatic field between the ruler and the papers.” (E₃₉)</p> <p>“The ruler attracts the peace of papers because of the electric field created by friction and the positive electric charges that are now on the ruler. As with the magnet and ferromagnetic objects, the ruler (magnet) will attract peace of paper (ferromagnetic objects).” (E₄₂)</p> <p>“By rubbing the plastic ruler with a piece of cloth, electrons are torn from this ruler, which becomes positive. Since paper is a neutral element, an electric field was created between the ruler and the pieces that attract that ruler.” (E₇₈)</p>	<p>When the rule is charging due to its friction, it creates an electric field. This field can exert a force (of attraction or repulsion) on a charged body from a distance. The space in which this force exerted an action is called the electric field. The electric field of negative and positive charges attracts each other. The explanations put forward by these students show that they have difficulty explaining the attraction of pieces of paper by using the notion of the electric field, as illustrated in Table 1.</p>
<p>Representation 3 (30/80–38%): The static energy in the ruler acquired due to its friction is transmitted to small pieces of paper and attracts them.</p> <p>“Rubbing the ruler against the wool allowed a transfer of static energy to it. So, since these static energy was intense, it could attract the pieces of paper towards it.” (E₃)</p> <p>“There is static energy in the ruler because of its friction with the fabric. This static energy was transferred to each of the small pieces of paper, which then stick to the rule.” (E₁₄)</p> <p>“Plastic transmits its electrostatic. Paper is easily attracted to plastic.” (E₄₉)</p> <p>“There is a transfer of electrostatic charges towards the neutral substance, here the paper.” (E₅₁)</p>	<p>Based on these explanations, it would seem to some students that the plastic ruler stores “static energy” due to its friction. Then, this energy was transferred to the pieces of paper hence their attraction. These explanations showed their conceptual difficulties in associating the electric charge and electric field concepts to explain the distant attraction of pieces of paper.</p>
<p>Representation 4 (16/80–20%): The friction of the ruler creates a magnetic field that attracts the pieces of paper from a distance.</p> <p>“I believe that when you rub the plastic ruler with a piece of cloth, the molecules stir and become a temporary magnet, which explains the effect of attracting objects around it. It is why small objects such as small pieces of paper are attracted to the ruler.” (E₁₆)</p> <p>“By rubbing the plastic ruler with the piece of tissue, we magnetize the ruler by stimulating its atoms by friction with the tissue and, as a result, we create an magnetic field which exerts an attraction on the pieces of paper.” (E₃₀)</p> <p>“I guess it is with the Law of Attraction. The ruler has previously loaded thanks to the friction between it and the piece of fabric, which created static electricity. A magnetic field was created (like with magnets), so the ruler could attract the paper within a certain radius without contact between it and the pieces of paper.” (E₇₁)</p>	<p>The explanations show that the students confuse the phenomenon of friction electrification with that of friction magnetization. In this last case, when we rub a magnet against a ferromagnetic material (e.g., iron, nickel) in the North–South direction, these materials turn into temporary magnets. This transformation results from the alignment of the atoms composing these materials. Note that these atoms are small magnets called micro–magnets.</p>

Other students’ (17/80–21%) answers are indecipherable to regroup them in given representations. By way of illustration, here are some advanced answers:

“I think the plastic and the piece of cloth together contain electrical charges which when rubbed together attract electrons from the pieces of paper.” (E₁₁)

“I think it is the static between the plastic of the ruler and the piece of cloth. This causes charges.” (E₂₉)

“This is because the ruler is in an environment where there is much electricity in the air. Also, the temperature of the environment is conducive to activate the latent electricity on the ruler.” (E₈₀)

5.5. Data Analysis: Question 5

The students’ explanations on the formation of lightning during a thunderstorm allowed us to identify four conceptual representations presented in Table 6, as well as the students’ numbers identified for each one and some of their responses.

Table 6. Student scientific knowledge about the lightning and their analyses.

Question 5: How does lightning form during a thunderstorm?	
Representation 1 (14/80–18%): Lightning comes from the meeting (or friction) between hot and cold air particles.	
<p>“It is the friction between hot and cold air rubbing together. This is why we see flashes of heat in the summer. Lightning does not need rain to form.” (E₂)</p> <p>“Lightning occurs when a mass of cold air and a mass of warm air meet in the air.” (E₇₁)</p>	<p>The answers given do not explain the formation of a lightning bolt. The air movements within the cloud create shocks between the particles: drops of water, ice crystals, sleet collide, rub against each other, which modifies their electrical charge. The largest particles (grains of sleet) become negatively charged when the temperature is below -15°C, and lighter particles become positively charged. Thus, inside a cloud, lightning is triggered when the difference in charges at the top and at the base of the cloud is intense.</p>
Representation 2 (18/80–22%): Lightning results from a collision or friction between (a) two clouds; (b) air and clouds; or (c) atmosphere and drops of water.	
<p>“The collision of two clouds together forms lightning.” (E₃₉)</p> <p>“The clouds meet, and under the effect of friction, there is an electric shock.” (E₇₉)</p>	<p>Lightning does not result from the collision between two clouds or because of their meeting. As outlined, the lightning strikes inside a cloud between two clouds or between a charged cloud and the ground.</p>
Representation 3 (12/80–15%): Lightning results from an encounter (or collision) between two negative and positive charges or the action of positive and negative charges in the clouds.	
<p>“I think it is the positive and negative charges of the cloud. The positives are at the top of the cloud, and the negatives are at the bottom. This creates the lightning.” (E₆₆)</p> <p>“Negative charges accumulate in a cloud, and when this force is great enough, these charges are attracted to those in the ground that are positive. The negative will join the positive, and that makes a flash.” (E₆₇)</p>	<p>These explanations are correct but incomplete as how to explain, for example, the movement of charges between the lower base of a negatively charged cloud and the positively charged surface of the ground, knowing that air is a good insulator. A slight discharge occurs at the base of the cloud, and it ionizes the air in its path. Thus, an electrical conductor channel is created, called a tracer. This slight discharge is followed by another, which will extend the tracer by a few dozen meters. The tracer is formed in zigzag and successive leaps with several branches in random directions but directed towards the ground.</p>
Representation 4 (16/80–20%): Lightning results from transfer charges between clouds and the ground.	
<p>“It is because of the transfer of electric charges from the cloud to the ground.” (E₁₇)</p> <p>“It is a transfer of charge between the clouds and the ground. A big visible shock.” (E₅₄)</p>	<p>There is indeed a charge transfer. On the other hand, as above, no explanation is given about the charges’ formation or how the lightning manifests. Furthermore, the term “shock” is not specified by E₅₄.</p>

For 20% of students, lightning formed due to charge transfer between a cloud and the ground. This representation is fair. However, there is a lack of explanations for this phenomenon, and it is the same for the other representations.

Twenty student answers (20/80–25%) were indecipherable to regroup in given representations. By way of illustration, here are some mistaken and confused reasoning answers.

“It is electricity that begins with atoms which are electrons that move in a given space like lightning. It is then an electric current between the cloud and the ground that produces light.” (E₃₈)

“Lightning is formed in clouds where hot particles contact cold ones. This collision causes positive and negative charges. These are then attracted to the Earth’s charge. The lightning thus formed then touches the ground directly or with the aid of an electrically conductive object.” (E₆₄)

“The creation of electricity comes from the friction between various substances. In the sky, during a thunderstorm, the clouds, therefore the fine water droplets in suspension, are very agitated by the high temperature causing the thunderstorm. This increase in temperature creates friction between the droplets, and at a certain point, this stored energy is released, which forms lightning.” (E₇₀)

“Ions come together from the clouds to the earth, the heat and light of their movement towards the ground as well as their large number makes them visible.” (E₇₇)

5.6. Data Analysis: Question 6

The students’ explanations concerning the shock that one can receive by touching a metal handle after having rubbed our feet on a carpet in dry weather allowed us to identify three conceptual representations presented in Table 7.

Table 7. Student scientific knowledge about electrical shock.

Question 6: How to explain that by rubbing our feet on a carpet in dry weather, we can catch a shock by touching a metal doorknob or another person?	
Representation 1 (24/80–30%): The charges produced by friction pass (or are transferred) from our body to the metal handle (electrons were transferring in the form of shock).	
“As we walk, our feet rub on the ground, especially on a carpet, and this creates an electric charge in us. This charge passes through our body towards the metal handle, capable of receiving an electric charge in contact with the handle by the hand. Thus, we undergo a slight electric shock.” (E ₂₅)	The explanations given are correct. These students explain the phenomenon in two stages: 1—the body charges resulting from friction and discharges by contact with the handle.
Representation 2 (12/80–15%): The human body is, therefore, a source of electricity	
“Our body also contains electricity, and when it touches metal, there is an exchange of charges. It is natural electricity.” (E ₃₂)	This explanation is flawed because the loads transferred from the body to the handle result from friction.
Representation 3 (18/80–22%): Touching the handle gives us a shock because the handle is charging with electricity.	
“Because in our body, there is static due to certain clothes that we wear (for example the polar) and that if the handle and charges positively, it will create a little shock.” (E ₁₅) “The handle is electrically charged; as we are conductors, we may receive a shock.” (E ₃₆) “The handle is loaded, and it is our body that allows the load to be released.” (E ₃₇)	These explanations are erroneous compared to a scientific explanation as synthesized in Table 1. The charges are not transferred from the handle to the body, rather the reverse. The body charges are due to the friction of the feet against the carpet. However, it is fair to say that the body is a conductor.

Twenty–five student answers (26/80–33%) were indecipherable to regroup in given representations. By way of illustration, here are some mistaken and confused reasoning answers:

“I believe this is due to our body temperature. The contact of the handle with the difference in temperature of our body creates a shock. Maybe we have too much static in us.” (E₂₇)

“Metal is a conductor of electricity, so when we are in motion, the static in the air comes into contact with our body, and when we touch the metal handle, we feel the shock.” (E₂₉)

6. Discussion

The data analyses showed that students’ knowledge about electrostatic phenomena appears in epistemological rupture with modern scientific knowledge. The representations of the student appear to be irreconcilable with those generally accepted in the scientific community. Table 8 lists the essential student knowledge encountered in the present study.

Table 8. Summary of students’ scientific knowledge and of their corresponding scientific knowledge.

Student Knowledge	Scientific Knowledge
There will be no static if we do not comb the hair in the same direction.	If we comb the hair in the same direction or both directions, we will have static.
The friction of the comb against the hair causes a transfer of protons and neutrons.	Rubbing the comb against the hair transfers electrons, not protons and neutrons.
The friction with the comb and the hair causes a transfer of protons and neutrons.	The friction between the comb and the hair causes electron transfer (negative charges).
When we rub a plastic ruler, it becomes electrified. The electrons bound from the nuclei of the atoms which constitute it loosen from the nuclei and become free.	When we rub a plastic ruler, it charges (positively or negatively). The bound electrons of the nuclei of the atoms which constitute it do not become free and they remain attached to their nuclei because the plastic is an insulator.
When there is friction between two objects, there is an exchange of electrons, and the two objects acquire opposite electric charges.	When there is friction between two objects, there is a transfer of electrons. Whoever donates electrons becomes positively charged and whoever receives electrons becomes negatively charged.
When there is friction between two bodies, there is an exchange of electrons.	When there is friction between two bodies electrons transfer from one body to another.
When we rub hair with a woolen cloth, we charge electrons positively.	When we rub the hair with a woolen cloth, the wool charges positively and the hair negatively, and the electrons are negatively charged particles.
The friction between two objects (e.g., piece of woolen fabric and a plastic ruler) creates an exchange of particles, electrons, and neutrons.	The friction between two objects (e.g., a piece of woolen fabric and a plastic ruler) creates a transfer of negative charges (electrons) from one to the other).

So, students’ scientific knowledge used to explain the electrification phenomena produced by friction is inadequate compared to the modern scientific knowledge related to these phenomena. Students used scientific terms, such as electric field, magnetic field, static energy, static electricity, static charge, positive charge, negative charge, and charged object leaning their logical thinking and everyday interaction with electrostatic phenomena. It is important to continue research to have more details on some of their answers.

Interestingly, these findings are consistent with many studies, including Suma et al. [6], which showed that high school students’ scientific knowledge about static electricity concepts is wrong compared to scientific knowledge despite teaching. According to him, for many students, “a balloon rubbed by silk will have the static electric charge that it can attract paper torn pieces. The term static electricity is identical to a static charge.” Furthermore, “plastic rubbed by cloth will get additional electrons from the cloth, that the plastic charge becomes positive; the cloth will have the negative charge so that the cloth and the plastic will attract each other.”

The identified student knowledge is highly relevant and appropriate to develop a two-tier test to rapidly diagnose the pre-service elementary teachers during their education at the university. Furthermore, one can build experiments confronting student knowledge.

7. Conclusions and Didactical Impact

While being clear about the limits inherent in qualitative research, the results have concluded that teachers in training construct misconceptions about static electricity. The data analyses indicate that they interpret the various phenomena related to static electricity by referring mainly to three representations. The first involves opposing charges whose

interaction seems to justify the observed phenomenon. The second refers to an equilibrium mechanism that redistributes charges between objects. The third relies on an accumulation of charges and possible flow in certain conditions. Other researchers have also identified these representations, as presented in the international literature review. So that these future teachers do not transmit their erroneous conceptions to their students, they should first discover the law of attraction and repulsion between rubbed bodies and between rubbed and non-rubbed bodies by carrying out different experiments. Unlike traditional teaching, they will analyze these experiments on a macroscopic scale, such as those performed at the beginning of the development of static electricity before understanding matter at the atomic scale. Then, they will study some historical considerations on the development of the particulate aspect of the matter. Pre-service teachers will have to confront their conceptual representations with scientific conceptions constructed throughout history to acquire scientific knowledge. In this regard, we must favor conceptual change strategies [23,24], which consist of comparing their misconceptions with those commonly accepted by scientists, as presented in the analysis of the responses put forward by the students concerning each of the six situations retained.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable for this search.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data is confidential in accordance with human research ethics.

Conflicts of Interest: The author declares no conflict of interest.

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