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Emphasizing the Role of the Insulator in Electric Circuits: Toward a More Symmetric Approach to Insulator and Conductor in the Instruction of Electricity

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Abstract

Instruction of electricity at the elementary and middle school level as recommended by the Next Generation Science Standards (NGSS), suggests that students should develop mental models that can be applied both to the open circuits of static electrical phenomena, and to closed electric circuits. They suggest starting the instruction of electricity by presenting experiences regarding electrostatic. The threshold concepts given by them are insulator and conductor take on a new importance, and common misconceptions concerning these terms should be acknowledged. The current paper reports the results of a learning study designed to avoid common pupil's misconceptions, especially regarding the insulator.

Keywords

concept Formation, elementary School Science, instructional effectiveness, curriculum design, misconceptions, experimental Groups, academic Standards, Science Activities

1. Introduction

The research described here suggests a change in the present curriculum (see description) and its application. The change consists of the addition of several worksheets that guide the pupils to a better understanding of the *insulator*. While the current curriculum (Levinger & Dresler, 1993) emphasizes the conductors of the current in closed electric circuits, it pays less attention to the insulator and its roles. We suggest to add experiences the exemplify the roles of the insulator such as leading the current into the operational parts of the insulator. The addition we suggest does not significantly extend the present curriculum, and improves the understanding of the roles of the insulator in the electric circuit. The core concepts of the research *insulator* and *conductor* are fundamental to the physics of electromagnetism, and to the understanding of the causal mechanism of the electrical devices that power modern civilization (e.g., electromagnets, motors and generators, home appliances).

Introducing the core ideas of electrostatics (static electricity) and electrodynamics (circuit electricity), into the 3rd to 8th grades' curriculum, has implications for understanding these underlying *threshold concepts* (Bar & Sneider, 2015). Threshold concepts are subject to common misconceptions, and can serve as barriers to acquiring core ideas. If students are to develop more sophisticated mental models of electrical phenomena involving both static and circuit electricity, it is essential for them to develop a more accurate and nuanced understanding of the relevant threshold concepts and include them correctly in their mental models. To reach this aim, exploratory learning study was conducted in two parallel elementary fourth grade level classes. One served as experimental the other as control, both classes were tested at the beginning and at the end of the study. The study was accompanied by presenting its test to a sixth grade of the same school as additional control group. This class had learned electricity twice according to the regular curriculum, and did not experience the additional exercises presented to the experimental group described here, dealing with the role of the insulator at the electrical appliances.

Our goal in this work is to help pupils to realize the different roles of the insulator, thus encouraging them to include the insulators in their electricity related mental models, such as the mental model of electric circuits, current and conductor.

1.1 Mental Models

A mental model is a representation of the world that each individual has in its mind. Each person has a unique understanding of how things work by acknowledging which entities within the world are relevant for some processes, and how these entities interact in a way that enables the specific process (Jonson-Laird, 1983). Mental models allow us to make sense of the world in our own way, and act in it as self-proclaimed rational agents. It is important to mention that any resemblance between a phenomenon and a mental model, which refers to it in one's mind, is unnecessary. The only necessary condition is that the mental model will suffice for the current aims of its holder, be these aims psychological, practical or theoretical. Mental models are flexible tools, and when being challenged by confronting evidence, they can react in a varying ways ranging from ignoring the newly encountered evidence up to a complete overhaul of the model.

The mental model is an all-encompassing tool, which helps us to navigate in the social world (e.g., how government works) or to learn about science and technology (e.g., how does a light bulb work). Regarding the natural world, mental models often helps us to make sense of natural phenomena and even to manipulate them. The literature of science education is abundant with researches aimed at exposing students' mental models regarding natural phenomena and this of technological application, such as the Earth's shape (Nussbaum & Novak, 1976), particulate theory of matter (Novick & Nusbaum, 1978), day and night (Vosniadou & Brauer, 1994), the water cycle (Bar, 1989), sound

(Hrepic et al., 2010), electric circuits (Gertner & Gertner, 1983), etc. Because electricity mechanisms are essentially invisible, electricity is often explained by analogies such as flowing water, moving crowds of people, moving trains, etc. Alas, no single analogy flawlessly corresponds to the phenomenon of electricity. In this research, we prefer to discard all these analogies and use a model of electricity that contains separation of kinds of electricit (of electricity charge at older ages) and force. Mental models are usually acquired through experience and common sense, hence the educational effort is not restricted to presenting students with new mental model, but also has to consider the mental models held by students pre formal education, which in the case of electricity is highly effected by the flawed analogies mentioned above. Within the educational process, students' views may be challenged by suggesting counter experiences, and or presenting other views through debates.

1.1.1 Mental Models of Electricity According to Prior Research

When pupils were asked how they imagine electricity, three general views appeared:

1) Electricity is connected to fire or danger; this view partially based on threats at home, and is enforced by instruction.

2) Electricity is some kind of flow; like black water (Azaiza et al., 2006). At older ages, electricity is connected to the movement of charged particles: they are referred mainly as electron, but also protons, neutrons, or simply particles. The pupils rarely know the accurate definition of the concepts they use.

3) Specific models for the flaw of the current in the circuit:

The majority of research studies conducted so far concerned on children understanding of electric flaw of current in circuits, and has resulted in an extensive literature about common misconceptions. McDermott and Shaffer (1992) found that many of these misconceptions persist into adulthood, and even many university students lack a conceptual model of simple circuits. This finding is vividly demonstrated in a video recording well known among science educators, which shows that even graduates from Harvard and MIT have difficulty using a battery and a single wire to light a bulb (Schneps & Sadler, 1997).

1.1.2 A Battery is a Source of Current and Contains Electricity in Some Form

The accepted scientific understanding of the battery is that is exploits a chemical reaction in order to separate charges, thus creating an electromotive force that causes electrical charges to move through a wire. Few students understand this idea, while many think instead of the battery as a source of electrical charge and current (Reif & Larkin, 1991; Niedderer & Goldberg, 1987; Lee, 2007; Gertner & Gertner, 1983). Considering the battery as a source of matter or electric charge, can result in the misconception that a battery is a container of an electrical substance (Park, 2001; Guisasola, 2008). A number of researchers observed that students imagined various liquids contained in the battery and flowing out of the battery into the wires (Lee, 2007; Lee & Chang, 2001; Hewitt, 2001).

Closely related to the mental model of the battery as a container of some sort of electrical fluid, is the "source and sink" concept of the electric current, a model that was initially recognized by Piaget (1929/1976). Pupils holding this concept assume that electricity is like a stream of water moving from a higher place to a lower place, without returning (Neidderer & Goldberg, 1987; Reif & Larkin, 1991). Although the analogue of flowing water makes some logical sense which helps students to distinguish between voltage (the force that propels the flow) and current (the total amount of water that flows over a given spot), some findings suggest that using the water analogy is counterproductive. The reason is that this analogy supports the misconceptions that the battery is a container of an electrical substance, and that of the current as not conserved.

1.1.3 Current is not Conserved

In a serial circuit, the current is the same throughout, so that every load (bulb, motor or resistor) has the same current running through it. This idea is not widely understood, and children express a number of alternative mental models (Osborne, 1981, 1983; Shipstone, 1984, 1985; Gertner & Gertner, 1983; Stockmayer & Treagust, 1996), which may be summarized as follows:

1) The one-polar model. This is the idea that the current flows out of one side of the battery and then "runs down" or "dissipates" so that each subsequent load gets less current. Closely related is the idea that the electric circuit is open (Bensegire & Closset, 1996).

2) The clashing current model. Another common misconception is that electricity flows out of both sides of the battery and collides in the bulb, where electrical matter is converted to energy. This model was found among learners of varying ages (Borges & Gilbert, 1999; Kärrqvist, 1985; Osborne, 1983; Shipstone, 1984; Driver, Guesne, & Tiberghien, 1985), including some pre-service and in-service teachers (Kucukozer & Demirci, 2008; Lee, 2007).

3) The decreasing current model. Current runs in one direction, and decreases after each component of the circuit. Hence, less current returns to the battery than originally left it (Shipstone, 1984; Lee, 2007).

A longitudinal study of students in the age range 8 to 12 in Israel found that the most common misconception changes with age (Azaiza et al., 2006). Among 8 year-olds the one-polar model was most common. Among 9 and 10 year-olds the clashing current model was most common. The decreasing current model was most common at age 11-12. By 12 years old, after the students have studied electric circuits as part of the national curriculum, only 36% of the students understood that the current is the same throughout the circuit.

Within the current research we conducted, the following mental model of conductor and insulator were discovered as common before instruction: while the Conductor is explained as "letting the current flow", and "the electric current moves in it", the role of the Insulator is only user related-preventing electric shock. Furthermore, these mental model regarding electricity mostly ignore static electricity, and has no place for it within the mental models of circuits.

1.1.4 Static Electricity is Different from Electricity in Circuits

Cohen et al. (1983), and Eylon and Ganiel (1990), found that students typically did not apply concepts of electrostatics while solving electric circuit problems, even though concepts of potential, field and capacity would be helpful concerning the solution of these problems. These studies indicated strong compartmentalization of knowledge as students saw electrostatics and electrodynamics as separate domains. Shen and Linn (2010) suggest bringing together the subjects of electrostatics and electrodynamics with a computer tutorial that explains a variety of natural phenomena, and laboratory observations using a model of the atom. Galili and Goihbarg (2005) also advocated introducing electrostatics into curricula in order to explain electric circuits. We agree that experience with both phenomena electrostatic and electro dynamics trough instruction (including both hands-on activities and computer simulations), can help to establish a conceptual bridge between static and circuit electricity, so students can come to realize that both concern moving electrical charges (Bensegire & Closset, 1996).

1.2 Effectiveness of Teaching Methods

Heller and Finley (1992) used *potential* instead of *current* to avoid misconceptions concerning batteries. However, this method was unsuccessful for elementary students. Shen and Linn (2010) had limited success with middle school students with defining electricity as a kind of energy. Shipstone (1984) tackled the decreasing current model by comparing the readings of two ammeters on both sides of a bulb. It was effective only for students older than eleven, while difficulties were observed through the age of 14 (Gauld, 1988). Dupin and Joshua (1987) tried teaching basic electricity to French students from 12 years old to the fourth year of university. They found the simplest models of electricity were eventually replaced with more complex ones, which still included misconceptions. Lee (2007) showed that teaching about the chemistry of the battery was unsuccessful at the elementary school level. To summarize, a number of research studies have demonstrated that middle school students have significant and persistent misconceptions about electricity. These can be briefly listed as follows:

1) A battery is a source of current.

2) Current is not conserved in electrical devices.

3) The only purpose of an insulator is to protect people from getting shocks.

4) An insulator *cannot* be electrified, while a conductor *can* be electrified.

5) Current cannot flow in open circuits.

6) Static electricity is different from electricity in circuits.

Those problems cannot be answered in this research alone. The aim of this research was to get a more symmetric view regarding the insulator and the conductor at the fourth grade, by extending the role of the insulator in pupils' mental models beyond being a shelter. Another insulator related problem, the problem of "The electrification of the insulator" was also part of this research, and will be presented in a future paper.

1.2.1 Current Curriculum as Influenced by the Technological Uses of Electricity

The history of the scientific and technological development of the electromagnetic force can provides useful insights for understanding the origin of concepts related to electricity, including misconceptions regarding the concepts *insulator* and *conductor* (Du Fay, 1734). One way of describing the history of the scientific study, and technological harnessing, of electricity, is as occurring in three very broad phases (Park, 1989; Wolf, 1961), electrostatic phenomena, current electricity and electromagnetism.

Historically, the development of each phase was logically built on prior phases, thus we feel that students will benefit from constructing their understanding of electricity by going through the three phases, approximately in the same order. But the Curricular focus on the many uses of electricity in everyday life (which is mostly done by the use of current carrying appliances), unfortunately had led to a neglect of electrostatic, while concentration on electrodynamics (Galili & Bar, 2008). This pragmatic approach of the curriculum leads to the misconceptions describe by Reif and Larkin (1991), and Niedderer and Goldberg (1987), and other misconceptions such as that an insulator cannot be electrified (Park, 2001), and the asymmetric attitude toward the insulator and the conductor when the insulator is regarded only as a "shock preventing" outer cover of the instruments.

The research described here ment to be a first step to address some of the misconceptions regarding electricity, and suggest a more symmetric view of the insulator and the conductor. To present our ideas about the role of the insulator we use the regular curriculum as our starting point. In this way, our suggestion would be an enhancement of the regular instruction instead of an overhaul. The regular curriculum is the one used in the elementary schools of Israel, the students learn electricity twice. The first stage is in grade four: "with the Current" (Levinger & Dresler, 1993), which introduces the electric circuit, its components, the electric current, a classification of materials into conductors and insulators, and vast applications of electricity in modern society, such as heat, light, industry, communication, etc. The second unit is instructed in grade six: "the Power Station" (Raziel & Dresler, 1990). This Unit introduces the generation of electricity in the power station and its transition to all the locations where it is used at home and outside it. The additional instruction suggested in this paper should be applied at the end of the first unit as a preparation for the second unit.

1.3 Research Goal and Questions

The Goal of the research was to introduce the roles of the insulator:

1) Protection of the user.

2) Protection of vulnerable parts in the electric circuit.

3) Separation of the conducting parts by an insulator in order to direct the current to the operational pars of the circuits, and enable their functioning.

4) Emphasizing the fact that separation is preventing short circuits.

From the list of these goals, only the first one is emphasized in the regular curriculum.

The research questions are:

5) What are the student's views about the role of the insulator, before carrying out the instruction?

6) How did these views change by applying regular and additional instructions?

7) Did these views change after presenting the second instruction unit at the sixth grade?

2. Method

The purpose of the current research is to help students unravel the misconceptions they hold concerning the limited role of the insulator (Novak & Gowin, 1984). The common misconception we revealed is that in their mental model of electric circuits the insulator functions only as to guard the users of electrical appliances from electrocution. This mental model reveals that that many students conceive the insulator not as part of the electric circuit by itself, but rather as a defensive addition to the circuit, which exist only to protect users. This misconception presents barrier to meeting performance expectations concerning electrical phenomena in elementary and middle school. What follows will be a set of learning experiences designed to address this misconception at the fourth grade level. The exercises, presented in the research description, are added to the existing curriculum, meant to serve as an addendum to the existing learning set, by focusing pupils' attention to inner parts of appliances and the roles of the insulators included in them, especially in guiding the current to the functioning parts of the equipment by separating conducting parts from each other.

2.1 Modifications to Fourth Grade Electricity Unit

The electricity unit is commonly taught to fourth grade to students in Israel (Levinger & Dresler, 1993). The Israeli curriculum is similar to that in most developed countries, including the United States, and consists of the following sections:

1) Uses of electricity, presented with pictures and text in a textbook.

2) Identification of the components of electric circuits, with which students build circuits.

3) Open and closed circuits that engage students in building several different circuits and observing what happens when a circuit is opened and closed.

4) Conductors and insulators, in which students build a test circuit, consisting of a battery, bulb, and two probes, to identify insulators and conductors.

5) Uses of electrical appliances and their merits, presented through text and pictures.

6) Electrical safety, including the danger of a short circuit and the role of fuses.

The primary goals of the existing unit are for students to appreciate the important role that electricity plays in our everyday lives, to recognize the potential dangers posed by electricity, and to learn how to safely use electrical appliances. As we know from prior researches, such units tend to support the misconception that the primary role of insulators in a circuit is to protect people from being electrocuted.

In order to improve the pupil’s views about the insulator and its roles, we added an additional component to the above unit—an opportunity for the students to explore the role of the insulating parts in various electrical components and in home appliances. As in the other experiences of the regular instruction unit, the added educational activities were carried out by the students through hand on experiences and were followed by discussions. While conducting these exercises, pupils observed the inner parts of the appliances and examined the roles of their isolating parts such as separating between the conductors and guiding the current to the functioning part (e.g., the light bulb). Within these experiences, student were confronted with functions of the insulators, which are crucial for the proper operation of the electric circuits, and unrelated to the human users, thus challenging their current mental models.

Discussions that followed the experiences were audio tapped, examples of these discussions were given in the text, pupils comments were marked by P, teacher' comments by T.

2.2 Subjects

Participants in the study were 60 students in two demographically similar fourth grade classes (30 in each class), learning in the same school. The average age of the students was 9 years old. As an additional control group, the written test was also given to 30 sixth grade pupils (average age 11) of the same school, who were already exposed twice to the standard instructions of electricity.

2.3 Additional Experimental Treatment

Experimental treatment consisted of presenting a number of worksheets to guide hands-on experiences, which aimed to focus the students' attention to the insulating parts in electrical appliances and their roles in guiding the current and guarding the inner parts of the equipment. This additional instruction consisted of two hours in addition to the traditional curriculum, and helped the students to become familiarized with the essential roles of the insulators within the electric circuit. The novel idea was to observe the crucial role of the insulator: separating between the conducting parts in the appliances, thus leading the current to the functioning parts of the electric circuit. One example of additional treatment is the bulb.

Students were led through the following steps in which they examined a small electric light bulb and identified its parts.

They discussed the insulating parts of the bulb, including those that can be observed, and those that cannot be observed. Parts that cannot be observed are: the connections of the metal rods that support the coil to the base of the bulb and its screw and the material within the screw.

1) The role of the insulator matter within the screw of bulb is to separates between the rods, rods connections to the screw and base were identified as guiding the current from the two ends of the battery to the bulb's screw and the bulb base.

2) This insulator separates between the two conducting parts the metal rods connected to the light giving coil. Thus enabling the current to reach the coil that emits the light of the bulb.

The students followed the following steps of observations and experiences:

3) The students observed that the bulb lit up when it was screwed into a socket and connected it to a battery. They then unscrewed the bulb and observed it closely using a magnifying glass, there by identifying its components.

4) They un screwed the bulb they used a test circuit, which consisted of another battery, bulb, wires and metal probes, in order to determine which parts of the bulb were conductors and which were insulators. The teacher drew the students' attention to the black plastic ring separating the metal screw from the

metal tip of the bulb's base, and the students identified this black spacer as an insulator that did not allow the two metal parts, the screw and the base to touch.

5) The students connected the two metal parts, which they identified as conductors; the screw and the base, by a small piece of metal, and then connected the bulb to the battery. The bulb did not light. They then disconnected the same two metal parts of the bulb and the bulb lit. They discussed why the bulb did not lit when the metal parts were connected.

T (Teacher): "Why there was no light in the bulb?"

P (Pupil): "The current came from the battery to the screw and moved straight to the base, through the metal it didn't have a chance to go to the coil".

P: "The current bypasses the coil".

T: "These is short cut the current does not reach the coil".

T: "How does the current go from the battery and back?"

P: "Current went from the battery to the screw, and then it went to the base and back to the battery"

T: "Did it reach the coil?"

P: "No".

T: "What would happen if a bulb did not have the black plastic insulator?"

P: "The metal parts would be touching, current will go straight from screw to the base and never reach the coil", "Electricity would go from one piece of metal to the other (in a short circuit) and the bulb would not light", "In other words, the insulator is absolutely essential for the bulb to light".

P: "Screw and base are separated by the insulator and current can go to the coil".

6) The students observed the coil (filament) inside the bulb and reported what they saw: "A tiny coil of wire supported on both ends by thin metal rods".

T: "Rods are made of?"

P: "Metal, they conduct the current".

P: "If those roads were made of insulation the current would not reach the coil".

P: "Rods must be made of metal since the current comes to the coil, and go out to the base".

Even though the students could not see inside the base, they inferred how it must look like inside and the materials of the parts they cannot touch. They made their mental model of the inner base parts.

Pupils draw the rods inside the bulb:

T: "Do the rods touch each other?"

P: "No they must be separated", "Touching will take current from one rod to the other". "Current will not reach the coil".

Pupils drew the inside of the base which they could not see. The Pupils made a mental model of the inside of the base:

P: "One rod touches the screw, the other the base".

T: "Rods are separated by?"

P: "An insulator, within the screw to prevent conducting parts to touch".

Most of the drawings showed that one rod was connected to the screw base, and the other was connected to the metal at the tip of the base.

The students compared their drawings; they realized that the rods should not touch each other inside the base. Pupils said that the rods should be separated by an insulator. In other words, the students created a mental model of the portion of the circuit that they could not see. A pupil said: "this insulator is the same as the black ring; it is an insulator and it separates between the conducting rods, black ring separates screw and base".

They further discussed the important role played by both the conductors and insulators in the bulb. The motion of the current inside the base of the bulb was described by a pupil as: "the current goes from the screw to one of the rods (attached to it), passes through the coil, which glows brightly, flows through the other rod, then down to the metal tip at the bottom". Pupils also said that the insulator within the base plays an important role by keeping the two rods separated in the base, as the black ring separates the screw from the base. The discussion was concluded by saying that "The insulator is necessary for the functioning of the bulb".

T: "Are you sure that the material within the base is an insulator?"

P: "Since it separate between the rods", "it avoids the shortcut".

Similar procedures were applied to explain other circuit components: pupils concluded that the switch should have metal parts that conduct upon touch, and an insulator base to stop current when metals are disconnected from each other. Switch must thus have both conducting and insulating parts. Another aspect of the insulator was demonstrated by the glass cap of the bulb. The role of the glass cap of the bulb was demonstrated, it was omitted (cut from the screw) and the coil was burned. Pupils identified this role of the insulator as to secure the coil. Pupils discussed a variety of home appliances that must have insulator parts inside them. Electric hitter and electric iron were used as examples; P: "The wires of the heating devises are covered with insulator"; "Metal parts do not touch, current is guided through hitting coil".

3. Results

Findings are shown in Table 1. The test included in table one is part of a regular test used in the system and validated by it. A T-Test between pre-tests' means showed no significant difference between the scores of the two classes, so the average pre-test scores are shown in a single column.

Table 1. Percentages of Students Who Correctly Answered Questions on the Assessments

Knowledge Domain	Pre-test Mean	Post-test Control	Post-test Experimental	Gain (Exp-Con)
Everyday use of electricity (3 questions)	82.3	85.5	92.0	+6.7

Electric circuit components (4 questions)	46.0	76.0	90.3	+14.3
Open and closed circuits (2 questions)	14.0	72.0	92.5	+20.5
Conductor-insulator dichotomy (9 questions)	48.4	76.1	89.7	+13.6
Electrical appliances (2 questions)	18.0	44.0	78.5	+34.5
Standard deviation (all questions)	0.23	0.24	0.24	

As illustrated in Table 1, it is clear that at the beginning of the class students were already knowledgeable about the everyday uses of electricity. However, they knew little about open and closed circuits and how electrical appliances operated. Both the control and experimental groups' knowledge improved significantly in each of these areas. However, the additional instructions given to the experimental group contributed significantly to the students' understanding of electrical phenomena, as measured by the post-test (Table 1). That is especially true for open and closed circuits and understanding the role of insulators and conductors in electrical appliances. A T-Test comparing pre and post tests of the control and experimental groups was significant at the $p < .001$ level in favor of the students in the experimental group. The effect of the instructional addition on the understanding is counseled by the closed form of the test, made to confirm with the existing instruction method.

To emphasize the effect of the additional instructions presented to the experimental group, the mental models of electric circuits regarding conductors as well as this of the insulators were examined by open question before and after the instruction. At the pre-test stage, most of the students (89%) defined a conductor as a material that enables the current to flow, and does not stop electricity. Third of them gave metals as examples of conductors. About quarter of the students also noted conduction of heat. One pupil mentioned being slightly shocked by an un-insulated conductor. Insulators were defined as the outer part of the appliance, which role is to protect the user.

There was little difference in the answers to this question between pre and post tests in regarding the conductor. At the post-test most of the students (90%) said that conductors are materials that enable electricity to flow, and metals were stated as examples of conductors. A few students mentioned power stations as a source of electric current.

On the pre-test, most students said that an insulator does not conduct electricity. At the post test, the experimental group's pupils noted three roles of the insulator: preventing shocks, sheltering inner parts of the appliance (P: "like in the demonstration when we took off the glass, the coil was burned"), and separating between the conducting parts in order to guide the current to the operational parts (P: "both the conductors and insulators are needed, they are both important"). Consequently, we can conclude from this study that students now understand that the purpose of an insulator is not only to protect people from getting shocks (a very important role), but also to channel the current, so that the device operates as intended (like the bulb and the switch). The mental model of the insulator was extended in this group when new roles were added to it. Answers did not change at the control group post test, and also when checked at sixth grade that had the regular instruction twice, in the fourth and in the sixth grades. Their answers were rather similar to those of the fourth grade control group; about half of the pupils said that the main role of the insulator is to stop the electric current when not needed. For example, P: "if we wish to turn the lamp on and sometimes we wish to turn it off", "the role of the insulator is to insulate", "to stop the flow of electricity". The same definition as given in the pre-test, that the role of the insulator is protection-shelter, was given by most pupils. These answers emphasize the importance of this research since the sixth grade pupils learned electricity according to regular method and may serve as a comparison to the experimental group. The role of the insulator to separate between the conducting parts, in order to avoid a short circuit, was not mentioned in the fourth grade control group, and when checked among two years older pupils, the definition of the insulator did not change: "its role is for shelter and to create an open circuit".

The views of pupils in previous researches and in the beginning of this research, assigned to the insulator only the role of protection, but did not discuss or emphasized its role within the electric circuit.

4. Discussion

The aim of this paper is to describe exploratory learning study that we have undertaken in order to address a problem identified in previous researches. This study was undertaken prior to the publication of the NGSS standards (2013), in which it is suggested that instruction of electricity will begin with electrostatics. However, we feel that instruction of some aspects of electrostatics should be held after an initial study of simple electric circuits. This instruction should include the idea of electric current, and the discrimination between conductors and insulators. This knowledge is crucial for the research described here. Thus, an experimental group of fourth grade students studied circuits and the roles of conductors and insulators in open circuits, closed circuits and electrical devices. The instructional approach in the present research consisted of adding the inspection of the inner parts of the appliances, and testing the role of the insulator within them. This exploration was relevant in extending the understanding of the role of the insulator in the circuit. The primary goal of the present study was to address today's curriculum and communicate the complementary roles of conductors and insulators in a continuous electrical circuit. In the literature review, we gave vivid evidence in the form of a video showing that even graduates from Harvard and MIT have difficulty using a battery and a single wire to light a bulb for the need of the introduction of the electric circuit. A sequence of lessons was presented to the students. During this sequence, fourth grade students carefully traced the electrical current inside a light bulb, within its screw, and within other items, noting the important role played by the insulator.

This involvement was quite successful in helping students understand how circuits function, and the roles played by both conductors and insulators in electrical devices. It was shown that these insights can be achieved at age nine when pupils are exposed to a special set of experiences added to the regular instructional set (Levinger & Dresler, 1993).

4.1 Further Rresearch

Recalling the common misconceptions about electrical phenomena summarized in our review of the literature, the present study especially addressed one of them: that the only purpose of an insulator is to protect people from getting shocks and being electrified. This role is certainly important and should be emphasized. However, this learning study suggested some useful interventions that can help students to extend upon this view. Before instructions, the mental models of the electric circuit among the pupils had no role for the insulator. The insulator only entered the former mental model when the model included interactions of the circuit with users. After the instructional involvement, the model extended to include the interaction of the insulator with the direction of the current in the electric circuit, and guarding some inner parts of the appliance.

The intervention suggested in the paper may become the seed to address certain other misconceptions such as the view that an insulator cannot be electrified (in progress by authors). This research resulted in a more understanding of the insulator and a more symmetric approach to conductor and insulator. We suggest adding a set of experiences and discussions in the form of the present research, to address this misconception. The addition suggested will include a survey of the views existed in the population and involvement together with pre- and post-test.

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