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# Pupils' Explanations of Natural Phenomena and Their Relationship to Electricity

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Changes in pupils' views concerning natural phenomena, some of which are related to electricity, were investigated. Inclusion of phenomena not related to electricity was used, to find out to what extent pupils of elementary school attribute these phenomena to electricity. The participants were elementary school pupils coming from a traditional population of a village in the Galilee. The sample contained 60 pupils from the fourth grade (aged 9 - 10). The pupils were questioned before and after receiving instruction, and the same pupils were also questioned at the beginning and end of the sixth grade (aged 11 - 12), following a second period of instruction. Qualitative explanations of the pupils show changes during age. Results show development from mostly mechanical explanations at ages 9 - 10 to preference of electrical explanations and wide use of concepts related to electricity at age 11, such as current, electrical charges, or electrons. Previous research and the results of this paper lead to a suggestion of a new approach to electricity instruction in elementary schools.

*Keywords*: Natural Phenomena Explanations; Elementary School; Electricity; Nature of Science

## Introduction

Electricity is a special domain of learning, commonly used in our daily life and the base of our technology. On the other hand, it is very hard to model, as the essence of its central concepts is abstract and formal. This paper will discuss a special aspect of electricity, namely the use of the concepts of electricity to explain natural phenomena. Electricity was introduced in elementary school at the fourth grade (age 9) and again at the sixth grade, age 11 - 12. At age 10 - 11, while learning about the human body and the weather, ideas and concepts of fourth grade are used. The domain is presented in a very descriptive and concrete form. In the fourth grade, the educator attempted to encourage pupils to construct knowledge which: 1) allows correct practical use of simple electrical devices; 2) implants very basic ideas (such as closed circuit, electrical flow, electrical source) regarding the nature of electricity in its scientific though simplified form of continues flow, whereas, in the sixth grade the focus shifts to electrical charges called particles, electrons, and charges as initiated by a few pupils; 3) Introduces the fundamental notions of circuit, battery, current, electricity consumers, often without their precise definitions, and 4) encourages the construction of some concepts (mental models) of electricity (such as electricity flow). However, the learning materials don't include references to electrostatic experiences. Surveying the previous research shows that some of the aims of this curricular program as applied may lead to misconceptions. Amending this curriculum will be one of the purposes of this research.

The understanding of learning adopted here was constructivism educational theory (e.g., Tobin, 1993; Novak & Gowin, 1984) recognizing the central role of learners' own spontaneous ideas on the conceptions of learners (taking into account the nature of science and its epistemology), and their strong interaction with the presented knowledge to determine the results of the process of learning. Addressing learners' ideas about the topic being taught increase the likelihood of success of the process. The ideas of two stages of elementary school pupils about electricity, and the effects of age and instruction on them were investigated. We chose to examine the aspect, which seems to be informative regarding the knowledge of electricity at these stages, which thus far has been less researched: pupils' notions about the relationship of electricity to natural phenomena. Pupils' ideas were investigated before and after each one of two units of instruction, currently used in textbooks in Israel: *With the current* (Levinger & Dresler, 1993) for fourth grade, and the *Electric Generator* (Dresler, Razial, & Einav, 1991). The four main reasons justifying the decision to carry out this investigation were: 1) Previous studies rarely included the aspect of explanation of natural phenomena concerning their relation to electricity; 2) most of the previous work dealt with older pupils (e.g., Solomon, Black, Oldham, & Stuart, 1985); while this investigation deals with nine years olds (fourth grade), which was the age of initial school instruction of electricity; and it was followed up by the further exposure at the age of eleven (sixth grade); 3) The participants of this research came from a traditional background, and it is interesting to find how they accept causal explanations regarding some natural phenomena that have traditional religious explanation in the script (Koren, 2006; Azaiza, Bar, & Galili, 2006); 4) providing an opportunity to overcome the misconceptions that appeared in previous research.

Teaching electricity at any instructional level, and especially in elementary school, is challenged by the abstract nature of this knowledge. Students observe and try to explain the macroscopic phenomena resulting from some microscopic processes, not directly observed or perceived. One could imagine that two bulbs connected in series, present more resistance than one, but one cannot observe electrical current or the processes causing resistance in the way one can experience movement of balls and their collisions. The lack of direct sense perception makes the instruction highly challenging. Pupils were required to construct mental images of complex phenomena they have never observed. Electricity in this respect, is similar to heat (Albert, 1978) and chemistry (Lee, 2007). Lee (1999) commented on two difficulties in students' learning of chemistry. From a macroscopic view, the mechanisms of chemical reactions are complicated, even the ones involved in our ordinary daily life. This complexity prevented students from constructing a practical physical image that would help them understand the specific scientific concepts related to the battery. The challenge was to find ways to present and explain such fundamental and highly abstract concepts as electrical current, voltage and resistance, necessary for the scientific account of the observed features of the explanations required. Participants used models to account for phenomena they observed. The learners explained the concept of resistance by comparing it with a bumpy road. The use of the water flow model of electric current and comparing electricity to "water in reservoir", can lead to mistaken views. The "water current" model is commonly found in related studies (Hewitt, 2001), which should draw attention to its applications and subsequent effects on the students (Lee, 2007). Every model, including the water model, has its limitations; each model represents only certain features of the real natural phenomenon (Oh, P. S. & Oh, S. J. 2010). It was assumed that at elementary schools the concept of voltage is too abstract, so it was replaced in the referred instructional units by the more concrete concept of "source" (the problems connected with this choice will be detailed). Some of the results, which will be described here, will be used to support ideas to facilitate the internalization of the concepts by the pupils mainly through maturity, and as a result of a second exposure. The particular form of instruction depends, of course, on the type of population, its age, previous knowledge, etc. Our aim was to reflect the used concepts and to elicit the explanations given by pupils aged nine and eleven through 12. We wished to examine how they construct their new knowledge, using their initial notions regarding the chosen domain. This would reveal the effects of the instruction and of the pupils' cultural background. The findings were expected to provide insights into the way pupils think and progress in their conceptions, and it might suggest different instructional approaches. The pupils investigated represented a special group of Arabic-speaking pupils from a small town. The participants attended a school belonging to the government education system (applied to about 80% of all pupils), which enforced eight years of obligatory education (the elementary school). The pupils' young age affected the nature of the curriculum, the learning materials, and the instructional methods. This will be further detailed in the discussion section of the paper.

## Previous Research

The research—dealing with children's ideas—about electric currents started in the early 1980s (Osborne, 1981).

### Observed Features of Electrical Circuits

Six models accounting for the electric direct current was recorded in various studies (Osborne, 1981, 1983; Shipstone, 1984, 1985):

1) The one-polar model, in which electric circuit is not closed. This model was found in Israel in third grade (age 8). Eighth graders in India discarded this model based on their practical experience (Sharma, 2008).

2) The clashing current model: current flows from the two poles meeting in the resistor (the "consumer" of electricity). Matter (current) changes into energy (Bar & Travis, 1991). This model was contradicted by using multi bulbs circuits (Azaiza et al., 2006; Gauld, 1988). The "two polarities, two currents" meeting to cause light model was commonly found in interviews with learners of varying ages (Borges & Gilbert, 1999; Kärrqvist, 1985; Osborne, 1983; Shipstone, 1984) and even existed among in-service teachers (Pardhan & Bano, 2001), and by an average of 43% of pupils' aged 11 - 17 (Driver, Guesne, & Tiberghien (1985). Pupils described two kinds of colliding ions that exert friction in the battery, to create electricity; resembling the clashing current model (Lee, 2007). This model was the most frequent among fourth grade pupils (aged 9) in Israel (Azaiza et al., 2006).

3) The decreasing current model: the current is running in one direction, each added component reduces the current by a certain amount (Shipstone, 1984).

4) The shared current among the circuit components model. Current travels in one direction around the circuit, the devices within the circuit share the current equally; however, less current returns to the battery than originally left it. This model is partially correct for series connection but creates difficulties regarding parallel connection, since all the resistances are added to calculate the current, and it is still non-conserving (Shipstone, 1984; Lee, 2007).

5) The model of a constant current (determined by the resistance of the whole circuit and the battery) throughout a closed circuit. The battery is a source of constant current. When two bulbs are connected with one battery, the brightness of the bulb "is the same" regardless of the circuit's features; the two bulbs share the same current, whether they are connected in parallel or in a series (Shipstone, 1984). Current does not reduce when coming back to the battery, the paralle and series current connections are not distinguished (Hewitt, 2001).

6) Current is determined by the resistance of the whole circuit including the inner resistance of the battery; current is constant in series connection, and shared between parallel parts. Current flows through a closed circuit and is constant through the whole circuit.

### Current Models and the Essence of Electricity

Models of current can be used in different every day domains (Neidderer & Goldberg, 1987; Reif & Larkin, 1992). The concept of current in everyday life is a general one and it became more precise in specific contexts, relating to a general understanding that derives from the source to the consumer. The same concept was also used in elementary school classes (battery as the source). Most currents in every day operated on the basis of the "sink; meaning that there is a motion of elements that move from one place to another without needing to return. This sink model seems correct for the flow of water, observed as moving from the high places to low ones (Piaget, 2008), and not coming back. Water also sinks in the ground. The conserved water model includes the water cycle, including phase changes that could not always be directly observed (Bar & Galili, 1994). The idea of a consumed curren is relevant for all models of reduced current, when current "changes" into light or heat. Consumed and constant current models created obstacles in understanding the differences between series connections and parallel connections of resistors or batteries (Lee, 2007; Shipstone, 1984). Research showed that understanding of the scientific model was not achieved at the elementary school stage, in spite of instruction (Tiberghien & Delacote, 1976; Shepardson & Moje 1999). The children used the explanation that the electrical current was "flowing" due to the battery or some other agent, eventually reaching the bulb. This flow was named "electricity" or "current." Many were not aware of the requirement of a closed circuit (an open circuit, first of the five models). Observations showed that the meaning of the closed electric circuit was not fully clear even at a much older age (Bensegire & Closset, 1996).

The conserved current model was created usually when current was perceived as consisting of separates particles, usually named electrons, protons or just electrical particles. This perception is usually created at about the age of 11 by a few pupils and continues through all the older ages (Azaiza et al., 2006; Lee, 2007). Research showed that pupils of 12 - 14 years, had problems to accept the particulate nature of matter (Novick & Nusbaum, 1978), including the concept of electric particles. The conserved current fits the idea of the particulate current made of separate conserved particles that do not disperse from wires covered by an insulator. This image was popular among pupils of secondary school and teachers of elementary and secondary schools (Osborne, 1981; Stocklmayer & Treagust, 1996; Borges & Gilbert, 1999). Pupils of all ages often relate electricity to fire and potential danger. Some inaccurate images continue at the age range of 11 - 14: "voltage gives power to the circuit," "battery gets empty," "current is consumed". Some images referred to materialization of electricity. Electricity was considered material like air, and the battery was its container: "Besides air, the hollow space in the battery is filled with invisible electricity, just like invisible air can fill up open space elsewhere" (Lee, 2007); rod ("a battery encloses tiny wires and/or small containers"); and water ("black water") "poured" into the battery, similar to refilling a tank with gasoline (Lee, 2007; Lee & Chang, 2001; Hewitt, 2001; Azaiza et al., 2006).

Research attempted to facilitate the teaching of electricity in various ways. Heller & Finley (1992) found that using the idea of potential instead of current, to account for the problem of consumed current, was not accepted at the elementary school level. Research regarding ages older than the elementary school showed that defining electricity as a kind of energy was not successful (Shen & Linn, 2010). Teachers introduced experiences to counter the decreasing current model by comparing the readings of two ammeters in the two sides of a bulb, (Shipstone 1984). This method was efficient only for ages older than eleven, and difficulties were observed also at age 14 (Gauld, 1988). Failure to convey this concept to fourth graders can be attributed to difficulty in recognizing the reading of the ammeter, as a valid realization of the intensity of the unseen current, which requires a degree of abstraction probably not found among 9 year olds.

Dupin & Joshua (1987), carried out an assessment of the effect of teaching the concept of basic electricity, to French pupils, ranging from the start of secondary school (grade 6, 12 years old), up to the fourth year of university. The simplest models did not last, but other "stronger ones" ("exhaustion", fading of current, constant current generator) remained relevant through many years of teaching. The Dupin & Joshua (1987) propose the hypothesis that certain misconceptions could be produced by the very way in which pupils overcome, in part, the first difficulties they meet, which poses a difficult problem for physics teaching.

### Relationships between Conceptions of Electrostatic and Electro Dynamics

Research into the understanding of electrostatics and electrodynamics (Cohen, Eylon, & Ganiel, 1983; Eylon & Ganiel, 1990) indicated a gap between the two domains. The concepts of force (electric force of attraction and repulsion) and potential were not used while solving electric circuit problems, and are generally ignored in the discussion of current flow in the circuits' resistors. A gap was created when electrostatics was learned before or after of direct current circuits.

Pupils indicated that induced electricity occurred in conductors and not in insulators, and that conductors can be electrified while insulators cannot (Guisasola, 2008; Park, 2001). These findings explained the gap between the simple experiments of electrostatics as charging by rubbing, and the world of batteries, bulbs, home appliances and electric currents. Shen and Linn (2010) suggested teaching electrostatic through the use of a computer program, and explaining phenomena observed at the laboratory and natural phenomena using the model of the atom.

### Cultural Effects

Some research addressed the relation between pupils' achievements in science and their cultural background. Lower achievements were registered among pupils coming from non-western societies compared with those of pupils coming from western countries (Baker & Taylor, 1995). Ethnically specific views concerning the natural phenomena of thunder and lightning were recorded in Muslim population with ideas not connected to electricity (Caillot, 2002). Traditional background was identified with low socioeconomic background **(**Glasson, Frykholm, Mahango, & Phiri, 2006; Sharma, 2008); this identification was not consistent with our sample: elementary school pupils at age 9, who came from different cultural backgrounds and ethnic origins (Jewish and Arab), were examined and compared (Azaiza et al., 2006). The results were more complicated than the comparison of achievements between western and non-western societies. Non natural explanations were observed in the two traditional groups of this research, but these groups were different in their approach to instruction (Azaiza et al., 2006). To suggest instruction strategies designed in view of the findings of previous research. The present research examined pupils from a traditional Muslim community, with an average background. The anticipated problems were related to collisions between commitments of religion and science; the research demonstrated how they might be overcome.

## Research Problems

1) How did pupils explain the phenomena presented to them, did they relate them to electricity (Piaget, 1930; Galily & Hazan, 2000)?

2) How did the explanations change from fourth grade (age

9 - 10) to sixth grade (age 11 - 12) levels of elementary school, as a result of instruction and of age?

3) How did pupils of a traditional background cope with attributing causal reasoning to natural phenomena?

# Methodology

## Sample

The participants of the research were elementary school pupils from the northern part of the country [Israel]. These pupils came from traditional Muslim communities and had an average economic background. The sample contained 60 pupils with an approximately equal number of boys and girls, both attended different classes at the same grade. All pupils were equivalent in their achievement of the learning. The pupils were examined four times: in the fourth grade, aged 9 and 10, and in sixth grade aged 11 and 12, each time before and after being exposed to instruction about electricity.

## Research Design and Stages

The research was a small quantitative one group study, addressed by a questionnaire and instruction. Open ended answers to the questionnaire were read by the researchers and analyzed qualitatively; it was a longitude research of one group study without a control group. Since the same compulsory curriculum was implemented in all the educational systems in Israel, it is hard to find a group that was not exposed to the instruction of electricity in fourth and sixth grades according to the learning materials described here. Our previous research, which compared three fourth grade (age 9) classes in geographically close schools, showed that in spite of the same instruction that used hand on experiences, discussions, and learning materials; the results were quite different. Each group showed its special characteristics (Azaiza et al., 2006). In each group there were points of strength and weakness, which do not coincide with the simple differences in the appeared quantitative achievements, (Azaiza et al., 2006). Comparison with other schools and classes will involve different teachers, different social backgrounds and different schools that will interfere with the results. The main aim of this study is to compare fourth and sixth grades twice exposed to the instruction of electricity. Still, the research will have to be repeated with a higher number of participants. The stages of the research are as follows, the same teacher taught all four classes:

1) Grade four pre-questionnaire.
2) First course in electricity ("*With the current*").
3) Grade four post questionnaire.
4) Sixth grade pre-questionnaire.
5) Second course in electricity ("*The power station*").
6) Sixth grade post questionnaire.

## Description of Instruction Materials

The instruction in both classes consisted of standard learning materials according to the compulsory curriculum, accompanied by hand on experiences and experiments, definitions of concepts, and class discussions. Each instruction section lasted about two months; instruction was performed two times a week.

At the fourth grade electricity is taught by using the book "*with the current*" (Levinger & Dresler, 1993). The teaching consisted of the following topics:

1) Description of the uses of electricity: electrical appliances are used for many purposes; 2) Operation of electrical appliances; phenomena related to electric current; 3) Ways to use electricity safely. This program specifies the effect of electricity on everyday life, and the safe use of electricity. The physical concepts demonstrated are the electrical circuit, conductors and insulators, the battery is demonstrated as the source and electricity as consumed, an approach criticized by Neidderer & Goldberg (1987). Electrostatics experiences were not included but the teacher answered children's questions; human body is presented as a conductor.

The second unit entitled "*Electric Generator*" (sixth grade, Dresler et al., 1991) contained the stages of generating electricity from the power station, and use of other sources of electricity, electrostatic in the form of thunder and lightning and electric fish were described as optional enrichments. Attention was focused on technology and safety. The physical concepts were source, current and energy. The effects of electricity are described by using the language of energy. Lee (2007) and Shen & Linn (2010) found this concept to be too hard for elementary school students and even for the junior high level. The classes' teacher reported answering pupils' questions about thunder and lightning and relating the phenomena to electricity.

## Questionnaire

The questionnaire consisted of seven problems that asked for explanations of natural phenomena related to physics, such as: thunder and lightning (Problem one), explanations of basic electrostatic concepts (Problems four and five), explanations of biological phenomena animal and plants (problems two and three), problems concerning the human body (Problems six and seven). The research questionnaire was constructed by the Azaiza et al. (2006). It was used in their former research (Azaiza et al., 2006), and revalidated for this research by researchers' discussions before applying it (see Appendix). The code names that will be used for the questionnaire are in accordance with the order of the problems: Thunder and lightning, luminescent fish, the shy lady, rubbing the comb, putting off the sweater, the conductivity of the nerves, living and dying.

# The Rational of the Research

According to the theory of constructivism and the research that followed the theory, pupils have pre-conceptions relating to science learning materials even before being exposed to its instruction. Our research shows that pupils 9 - 10 years of age knew the word electricity, and related it to electricity many technological uses (Galili et al., 2008); from house hold appliances to street illumination, theater, industry and so on; before learning about it. At the beginning of this research, we tried to find out to what extent pupils attribute electricity to natural phenomena before being exposed to instruction (**Table 2**). Some children aged 9 to 12 referred to lightning as "the electricity in the sky (privet communication). On the basis on these initial findings (**Table 2**), we continued to check if this use of electricity would increase following exposure to formal instruction of some basic notions of electricity (see introduction). The research continued after a period of about 15 month at the age of 11, in applying a second pre-questionnaire. Initially, we had hoped that electricity concept would be internalized during this period, following further instruction of related domains. Connections were anticipated due to a course in biology (the human body) that the pupils were exposed to in grade five, aged 10 - 11 and leaning about the weather. In this research we wished to find what electrically related ideas pupils used to explain a veracity of phenomena including those which were not related to electricity: to find out how do pupils use this concept to explain "the unknown". The questionnaire (Appendix) was not graded and not intended to check correctness of answers, just to follow the pupils' ideas and the changes that occurred in them.

## Analysis of the Results

The results were analyzed according to a set of schemes suggested by Piaget (1930, 2008). The content of specific answers was classified according to the schemes: *description*, giving a description of the phenomenon without adding any reasoning (*descriptive*); *personification*, use of personal properties for animals or inanimate objects (*personification*); *teleological*, assuming that the phenomenon occurs in order to achieve a given purpose (*purposeful*); *causal explanation* suggesting some natural reason to the phenomenon (*causal*); and intervention of some *non-natural* agent to cause the phenomenon (non-natural). Within the scheme of the causal explanations a sub scheme of electrical causal is also defined when an electrical reasoning was suggested (**Table 1**). The specific aspects of the explanations given to each question within these schemes, the facets (Galili and Hazan, 2000) were changed according to the content of each question. The same classification scheme was used in all the stages of the research, depending on problem, learning and age. Additional explanations specified the meteorological conditions, for the appearance of lightning and thunder, they consisted of a small part of the causal electrical explanations based on learning about the weather at age 10; they are described separately in the text. The categories of explanations are presented in the explanation theory (Berland & McTigue, 2009; Smolkin, McTigue, Donovan, & Colman, 2009; Kuhn & Reiser, 2009). The answers were read and coded by two researchers separately, discussed, and the scheme was agreed upon. Inserts that exemplify each scheme are given in **Table 1** and in text.

# Results

## Pupils' Explanation Regarding the Phenomena (Research Question Number 1, Table 1)

**Table 1** contains a sample of responses given by pupils of all stages, classified according to the adopted classification scheme. Answers about meteorological conditions are included in the discussion and will be exemplified later. The examples given in the tables are named according to the code defined previously.

Answers in **Table 1**, were divided among all the schemes. The schemes: descriptive, personification and non-natural explanations appear more often in grade four, while causal and mainly electrical causal tend to accumulate toward grade six. More detailed quantitative results will be presented in the other tables. Similar to Shen & Linn (2010), there is no reference to energy in **Table 1**.

**Table 1.**
Fourth-grade and sixth-grade students explanations of natural phenomena.

| Question | Scheme | Grade |
|---|---|---|
| | Descriptive | |
| Luminescence fish | "The fishes are colored" | 4th |
| Lightning and thunder | "The lightning is light and the thunder is sound" | 4th |
| Lightning and thunder | "The lightning shines the sky and the thunder makes a sound" | 6th |
| "Shy lady" - plant | "She is beautiful and shy" | 4th |
| Question | Personification | Grade |
| Lightning and thunder | "The clouds are crying and angry" | 4th |
| Removal of sweater | "The mosquitoes are making this noise" | 4th |
| "Shy lady" | "She doesn't like the sun" | 4th |
| "Shy lady" - plant | "she is afraid" | 6th |
| Question | Teleological | Grade |
| Lightning and thunder | "The lightning gives the message that the rain is close" | 4th |
| Lightning and thunder | "The rain gives the message that the spring is close" | 4th |
| Lightning and thunder | "The lightning gives the rain" | 4th |
| Luminescence fish | "The fish give the light for finding the way in the sea" | 6th |
| Luminescence fish | "The fish is lightning because of the darkness in the depth of the sea" | 6th |
| Luminescence fish | "To find food" | 4th |
| Shy lady | "It pretends sick in order to not pick it" | 4th |
| Hitting the leg | "It helps us for movement" | 6th |

**Continued**

| Question | Causation | Electric | Grade |
|---|---|---|---|
| Lightning and thunder | "The wind causes crash between the clouds" | - | 4th |
| Lightning and thunder | "It's occur when the clouds are crashing" | - | 4th |
| Lightning and thunder | "It's occur when the clouds were crashed, then the static electricity was created" | Causation-electric | 6th |
| Lightning and thunder | "The clouds were crashed' then the static electricity was created" | Causation-electric | 6th |
| Lightning and thunder | "When the clouds get together" | - | 4th |
| Luminescence fish | "When the fishes absorb the light" | - | 4th |
| Hitting the leg | "Because the muscles were shrunk" | - | 6th |
| "The electricity that leaved our body", life and death | "The soul is like electricity when it leaves the body the person will die" | - | 6th |
| Luminescence fish | "When the light falls down on the fish | - | 6th |
| The comb and the hair | "Because of the friction between the hair and the comb, we got static electricity that we heard" | Causation-electric | 6th |
| Removal of sweater | "When the wool touched the hair we got spark that gives electrons" | Causation-electric | 6th |
| Removal of sweater | "The friction created (electricity) from conductor strings. When it closed to our body we feel short circuit" | Causation-electric | 6th |
| The person who died when the electricity was leaving his body | "Our body is conductor. Especially our heart. When the heart stopped we can say that the electrical circuit was open" | Causation-electric | 6th |
| **Question** | **Non-natural (God)** | | **Grade** |
| Luminescence fish | "The fishes are emissaries of our God in the water" | | 4th |
| The hair and the comb | "The hair prays to god" | | 4th |
| "The electricity that leaved our body" | "Our god put the electricity in our body and takes it when we died" | | 6th |
| Lightning and thunder | "This phenomenon is sanctified and God right" | | 4th |
| Lightning and thunder | "It's indicated that the god is angry" | | 4th |
| Electricity images | "The soul of the things" | | 4th |
| Lightning and thunder | "Phenomenon that indicated about rain and blessing from God" | | 6th |

*Direct citation is in parenthesis additions in parentheses.*

## Distribution of Answers according to Age and Instruction (Research Question Number Two)

The distribution of quantitative percentages of the answers, are presented in **Tables 2-4**. Those Tables present the calculated numbers and percents of the appearance of each scheme (listed in **Table 1**) at each stage.

In the Distribution before instruction (**Table 2**) answers were distributed among all the schemes. Many were included in the descriptive and personification schemes. Description of phenomena without explaining may be attributed to lack of knowledge (many pupils did not answer). In their answers to five of the problems (1, 2, 3, 4, and 7), the pupils referred to a non-natural source: to God. This kind of explanation did not occur in non-traditional groups of the same age but occurred in other groups of the same age from a traditional background (Azaiza et al., 2006). The percentages of causal answers were generally higher (questions 3, 4, 5) than the percentages recorded in the other schemes. After the first exposure (age10) to instruction, the pupils' responses changed and point at the relevance of the chosen schemes to each problem (see below). The percentage of the causal explanation scheme was increased, while the percentages of the personification, teleological and non-natural source, were decreased (**Table 2**). The average percentage of causal electric schemes did not change (**Table 4**). For the classification of answers given by grade six pupils see **Table 3**.

The change that occurred towards sixth grade is quite dramatic even before the pupils were exposed to further instruction (**Table 3**). At this stage, the pattern of the explanations became quite different from the one observed in the fourth grade. Percentages of causal explanations increased considerably, reaching the average of 76%, while the other kinds of explanations reduced. The percentages of electrical causal explanations, regarding the luminescent fish and the shy lady (not connected to electricity), were smaller than in the other problems, and they decreased after the second instruction. Many pupils did not answer the problem of the shy lady (20% did not answer, 18% gave a descriptive explanation after instruction). The general increase in the percentage of the causal explanation coincides with the theory of Piaget (1930), and it is connected to the rise in age.

 

**Table 2.**
Quantitative distribution of student's explanations for natural phenomena in fourth grade before and after instruction (%).

| 4th grade | Descriptive | Personification | Teleological | God Source | Causation | No Answer |
|---|---|---|---|---|---|---|
| Question | | | before | | | |
| 1 | 25 | 25 | 25 | 13 | 13 | 0 |
| 2 | 25 | 0 | 25 | 13 | 25 | 12 |
| 3 | 13 | 13 | 13 | 13 | 38 | 10 |
| 4 | 13 | 6 | 0 | 6 | 38 | 37 |
| 5 | 13 | 19 | 0 | 0 | 38 | 30 |
| 6 | 13 | 25 | 25 | 0 | 19 | 18 |
| 7 | 25 | 13 | 0 | 19 | 25 | 18 |
| Total | 127 | 101 | 88 | 64 | 196 | 125 |
| Average | 18 | 14 | 13 | 9 | 28 | 18 |
| Question | | | after | | | |
| 1 | 25 | 19 | 19 | 0 | 38 | 0 |
| 2 | 24 | 0 | 19 | 0 | 21 | 36 |
| 3 | 13 | 0 | 0 | 0 | 44 | 43 |
| 4 | 0 | 0 | 0 | 0 | 59 | 41 |
| 5 | 11 | 14 | 0 | 0 | 50 | 25 |
| 6 | 46 | 21 | 0 | 0 | 25 | 8 |
| 7 | 50 | 0 | 0 | 13 | 13 | 24 |
| Total | 169 | 54 | 38 | 13 | 250 | 177 |
| Average | 24 | 8 | 5 | 2 | 36 | 25 |

**Table 3.**
Quantitatively distribution of student's explanations for natural phenomena in sixth grade, before and after instruction (%).

| 6th grade | Descriptive | Personification | Teleological | God Source | Causation | No Answer |
|---|---|---|---|---|---|---|
| Question | | | before | | | |
| 1 | 0 | 0 | 4 | 1 | 93 | 2 |
| 2 | 2 | 2 | 23 | 7 | 42 | 12 |
| 3 | 2 | 9 | 0 | 0 | 69 | 26 |
| 4 | 2 | 0 | 0 | 0 | 96 | 2 |
| 5 | 5 | 0 | 4 | 0 | 80 | 11 |
| 6 | 8 | 0 | 8 | 0 | 70 | 14 |
| 7 | 3 | 0 | 0 | 0 | 85 | 12 |
| Total | 22 | 11 | 39 | 8 | 535 | 79 |
| Average | 3 | .2 | 6 | 0 | 76 | 11 |
| 6th grade | Descriptive | Personification | Teleological | God Source | Causation | No Answer |
| Question | | | after | | | |
| 1 | 0 | 0 | 1 | 1 | 98 | 0 |
| 2 | 2 | 2 | 36 | 7 | 42 | 17 |
| 3 | 18 | 0 | 0 | 0 | 60 | 23 |
| 4 | 0 | 0 | 0 | 0 | 93 | 7 |
| 5 | 3 | 0 | 0 | 0 | 85 | 12 |
| 6 | 5 | 0 | 7 | 0 | 85 | 3 |
| 7 | 0 | 0 | 0 | 0 | 88 | 12 |
| Total | 28 | 2 | 4 | 8 | 551 | 74 |
| Average | 4 | 0 | 6 | 1 | 79 | 10 |

**Table 4.**
Percentages of electric causation explanations for the natural phenomena (%).

| Question | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Average |
|---|---|---|---|---|---|---|---|---|
| Test of 4th grade Pre | 7 | 29 | 12.5 | 27 | 13 | 19 | 13 | 19 |
| Test of 4th grade Post | 22 | 13 | 12 | 19 | 15 | 18 | 9 | 18 |
| Test of 6th grade Pre | 50 | 35 | 19 | 74 | 51 | 23 | 37 | 41 |
| Test of 6th grade Post | 67 | 19 | 17 | 76 | 58 | 29 | 57 | 49 |

### Causal Electrical Explanations

The percentages of causal electrical explanations given within the causal explanation appear in **Table 4**. Note that the percentage of explanations that attributed these phenomena to electricity did not increase in the fourth grade after instruction but increased considerably towards sixth grade (**Table 4**).

### Statistical Analysis

The $\chi^2$ questionnaire analysis showed a significant increase in the percentage of causal explanations, in relation to all other kinds of explanations, at the end of fourth grade, ($\chi^2$ 9.73; $P < .008$). A highly significant change was also observed between the second questionnaire of fourth graders and the pre questionnaire at the beginning of sixth grade, ($\chi^2$ 333.8; $P < .00001$). The second exposure to instruction resulted in a small change in causal explanations ($\chi^2$ 1.79 $P < .619$). This was also accompanied by the doubling of percentage of causal electrical explanations the in sixth grade (**Table 4**). After instruction the percentages of causal electrical explanations increased for all the answers to the problems related to electricity, and decreased in the ones not unrelated to it. Electrical explanations increased in13% regarding relevant problems.

## Detailed Results

We aimed to find the extent of the use of electricity in explaining natural phenomena. Three approaches to these phenomena will be detailed:

### How Do Thunder and Lightning Occur?

Following the instruction provided in fourth grade the percentage of causal answers regarding this problem increased (**Table 2**). Most answers given at that age and by a few of sixth graders were mechanical, suggesting friction, collisions and active motion as causes. Participants, backed by the teacher's answers to their questions, concerning this problem, used electrical explanations, this use increased at age ten (second exposure to the questionnaire, **Table 4**). At the younger ages explanations were short and limited in their reference to electrical concepts: "it is caused by electricity". Electrical explanations consisted of the majority of causal explanations at age 11 before instruction, friction and collisions were supposed to create electrical charges, causing thunder and lightning in varying conditions:

1) "Collisions of clouds create electrical charges seen as light: the lightning and voice: the thunder";

2) Thick storm clouds and currents of up and down going clouds (air motions);

3) Humidity: "the clouds contain water so there is high humidity", and it "charges it";

4) Temperature, high or low, caused thunder and lightning;

5) Air and clouds became conductors;

6) Separation of charges;

7) Opposite charges: "the charge in the cloud is opposite to the charge of the earth";

8) "The electrical pressure between the clouds is high," (sixth grade after instruction);

9) Delivery of electrons between clouds created a closed electric circuit and "initiated light in the form of lightning".

A composite of several aspects is connected to the water cycle: "Water changed into vapor that filled the clouds, the clouds collide, thus electric charges were created, and electricity is created in the form of a spark".

Lightning was described as an electric spark that happens between the clouds and the earth; "thunder is a vocal effect of the collision between the clouds, resulting from emptying the clouds of opposite charges". A hint is given to a wave or shock: "the air will expand and then contract rapidly to cause the thunder". The meteorological conditions for thunder and lightning were given by 10% of the pupils (6 pupils) within various levels of accuracy, together with the electrical causation. These answers resulted from lessons about the weather and non curricular sources: books and TV such as the National geographic television programs about lightning. Suggesting electrical causation was influenced by experience made in the class: "this is a natural electric phenomenon that contains delivery of electrons between clouds, which created a closed electric circuit and initiated light in the form of lightning". These descriptions extended the electrical causal scheme and transferred it into a new domain. The electrical concepts used were: electrical charges separated to negative and positive charges, current, becoming a conductor, electric sparks that emptied charges caused by collision (the term used here and elsewhere was empting rather than neutralizing). Some of the causes of thunder and lightning, sighted above, may be inaccurate from our scientific point of view, but they are very natural to pupils, and accepted as such: "humidity makes it charged" (may be since children are cautioned not to approach electricity with wet hands), "thunder is the voice created from the low temperatures", they all show how pupils use their knowledge and conjecture to make sense of the world.

**Electrostatic Phenomena:** Causal explanations for these phenomena were more frequent than concerning the other phenomena. 9 - 10 year olds gave mostly, mechanical explanations (similar to answers regarding the thunder and lightning problem): "since we rubbed the comb", "since we pulled the dress". Pupils related to electricity before being exposed to instruction, percentages remained rather small after first exposure, **Table 4**. Electrical explanations at fourth grade were general and did not contain details of the suggested mechanism: "rubbing and collisions caused electricity". Electrically related explanations increased significantly at age 11, with about 70%, addressing the comb problem, and about 50% addressing sweater problem (**Table 4**). We believe that this percentage would increase if we include the electrostatic experiences in elementary School. 11 - 12 year olds gave detailed mechanism for the experiments and used the notions of delivery of electrons and separation of charges before and after instruction: "when rubbing the comb, electrons moved from (or into the comb) and then the comb is electrified and attracts the pieces of paper". The explanations analyzed according to facets and schemes for thunder and lightning and electro-static phenomena are given in **Table 5**.

**Human Body:** Concerning these problems three main stages explanations were identified. Stages:

1) Attributing *Non-natural source*, typical to the traditional background of the participants (**Table 2**), since it was not found in non-traditional groups (Azaiza et al., 2006). After the instruction in fourth grade, the explanations referring to this source appeared only with regard to the problem of living and dying. In the sixth grade non-natural scheme was rare.

2) *Change in the percentages of the descriptive scheme through instruction*: this facet is unique to problems that regarded the human body. The average percentage of descriptive explanations in fourth grade, after instruction, did not decrease, in fact, they actually increased (**Table 2**), increase was most apparent in Human body problems. About half of the answers to the human body problems were within the descriptive scheme (**Table 2**), accompanied by a decrease in the choice of this scheme in problems two, three, four and five. The increase in choosing the descriptive scheme concerning the human body was followed by a small percentage of causal and especially electrical causal explanations, average of causal explanation for both problems did not change (at the end of fourth grade: age 10, only 13% chose causal answers, only 10% gave causal electrical explanation, regarding life and death, **Tables 2** and **4**). In contrast causal explanations for thunder and lightning, and electrostatic problems increased, while the use of descriptive scheme decreased. These findings require special attention to this kind of problems and especially to life and death. Pupils' answers to these problems are mostly interesting regarding question three of this research:

**Table 5.**
Analysis of results in the form of facets and schemes.

| Facets | Facets | Schemes |
|---|---|---|
| Thunder and lightning | Electrostatic | |
| Clouds collide | Collisions | Mechanical |
| Friction of clouds | Rubbing | |
| Lightning as a spark | | |
| Thunder as voice | | Effect of electricity |
| Thunder as a shock | | |
| Delivery of electrons | Delivery of electrons | |
| Separation of clouds | Separation of clouds | |
| Empting of charges | | |
| Closed electric circuit | | |
| Humidity created electricity | | Electrical causation |
| Temperature electricity | | |
| Cloud became a conductor | | |
| High electric pressure | | |

### How Will Pupils of a Traditional Background Cope with the Physical Explanations Connected to Electricity of These Phenomena (Research Problem 3)?

The findings can be attributed to the background of the pupils. For pupils coming from a traditional background, who were not yet ready to either accept causal explanations regarding the human body problems or to relate them to electricity, the alternative of description seems logical. Descriptive explanations were found with regards to the life and death problem even in sixth grade. Their frequency is nonetheless reduced. This occurred after the pupils had a course about the human body that used notions of electricity of fourth grade. Pupil's antagonism against causal explanations reduced, 85% of the participants adopted causal explanations; and 57% gave causal electrical explanations, before the second instruction (**Tables 2** and **4**). This choice was sometimes accompanied by indicating God interference as the initial cause of the phenomenon: "god is responsible for life and death but he uses electricity or other physical means to do it". The progression towards accepting the electrical explanations occurred in two stages: descriptive explanations were observed instead the non natural scheme, together, with a relatively high percentage of pupils who did not answer. The use of electrical explanations appeared at the second stage together with some comments that explained how the pupils accepted them. The explanation was causal, but, "God interferes in the natural process" as an initial cause that works through several natural agents ("God puts off the electricity"). This kind of complex answers appeared in the minority of the instances, in the sixth grade, along with causal and electrical answers. This explanation shows how the pupils overcame their resistance to use causal explanations for life and death, and the conductivity of the nerves, (research question no 3): "I think that this is correct since the human body conducts electricity and full of electric charges especially the heart"; "We know that when the heart beats the electricity functions as it should"; and "when s/he dies the heart stops, and so the electricity".

**Extension of the Use of Electricity:** Pupils extended the use of electricity to phenomena not related to it. They connected the luminescent fish and shy lady to electricity. The shy lady, phenomenon was explained as caused by electricity or by heat, which was further elaborated: "it is since electricity causes heat". Regarding luminescent fish explanations originated from 1) Over generalization: "luminescent fish emanate light because of electricity, since electricity creates light"; were connecting every light to electricity: "electricity is needed to light the bulb, thus every light is due to electricity". This known logical failure mixes reason with result. 2) Identifying luminescent fish with electric fish. 3) Attributing this phenomenon to the conductivity of the water: "this light is caused by electricity passing through the water, since water conducts electricity". 4) A non-electricity explanation: the luminescence of the fish is due to reflection, was also found among physics students (Azaiza et al., 2006), who study optics. The electrical explanations observed in this research are justified from the point of view of the pupils. These explanations were accepted by us on the grounds that the pupils do not know the answers and use electricity to make sense of their world.

# Discussion of the Results

## Mutual Schemes and Different Frequencies of Chosen Answers

The answers were distributed between schemes suggested by Piaget (1930). Answers that related to the different schemes appeared among the replies to all the problems but in different frequencies, which changed with exposure to instruction and age.

Each problem came from a different domain demonstrated a different choice of explanations, and different reaction to instruction. Descriptive, common before instruction, hinted mainly at lack of knowledge and was sometimes accompanied by a relatively high percentage of no answers (**Table 2**). This scheme had especial role in human body problems as sighted. Descriptions showed that pupils were not sure which came first: "thunder precedes the lightning", or "this is the lightning that has a very high velocity". Personification appeared regarding the thunder and lightning, due to the intensity of the phenomena: "the clouds quarrel, or weep and pray", "they are angry". For the shy lady: "the plant is afraid and it is shy", this answer might represent the fragility of the plant that protects itself from heat and touch, or related to its name. Teleological explanations regarding thunder and lightning were related to the strong connection between thunder, lightning and rain; since folklore; and scripts described thunder and lightning as anticipating rain and even causing rain. For the luminescent fish, the teleological explanations have an evolutionary sense: "the light helps the fish to find food, navigate in the dark; and protected it: enabling the fish to escape from enemies". Teleological explanations are accepted nowadays as part of the explanation theory, according to Berland and Reiser (2009), Kuhn and Reiser (2009) and Smolkin, McTigue, Donovan and Colman, (2009).

**Causal Answers:** causal answers appeared among the answers to all the problems, especially in grade six when personifications, non-natural, descriptive and no answer schemes decreased significantly (**Table 3**), their frequencies were on the average higher than those of the other explanations. Causal explanations sometimes resembled teleological: "shy lady shrinks from the heat since it harms her" (teleological phrase would be "she avoids the heat and touch in order not to be harmed"; **Table 1**).

Answers contained details that should be dealt with in the class; they pose a challenge to the teacher to lead the class closer to the accepted scientific views. To achieve this purpose, the teacher needs a lot of disciplinary and inter-disciplinary knowledge to evaluate the learners' answers and to relate to the kernels of truth in them (Vygotsky, 1986). This research showed that the pupils internalized the learning of electricity, since when they watched the National Geographic; they were able to repeat some of its explanations coherently. On the other hand, the same observation showed how hard it is to separate the influences of maturing, motivation and media on the concepts of the pupils. A clean separation of variables is quite hard in long term research.

## Developmental Patterns in Pupils Explanations

Before instruction Non-natural source was attributed to thunder and lightning: "this phenomenon questions on rain and blessing from God", sometimes accompanied by citations from the Koran: "the Koran that show that the water and the rain come with the thunder and the lightning, they symbolize that strong rain is coming with the blessing of the Lord" non-natural is sometimes mixed with teleological. Exposure to instruction resulted in two stages in the pupils' conceptions. Most fourth graders held the clashing (colliding) current (Azaiza et al., 2006) and colliding ions in the battery conceptions Lee (2007). Collisions and friction explained, the mechanism of rain falling from the clouds (Bar 1989), thunder and lightning and electrostatic experiments, nerve conduction, **Table 1**. Piaget (1930) concluded that pupils' answers at this age are mechanical, they used the mechanical scheme through the facet of "collisions and friction" to account for many events (Galili & Chazan, 2000), **Table 5**). Electrical current was viewed as a continuous flow, and the water analogy enforced non-conserving ideas about current; particles were not mentioned. Starting from about age eleven two new conceptions of electricity developed: a few of the pupils' began to describe electricity as made of particles, which they call electrons or protons. They used more advanced models of electric current (Azaiza et al., 2006), the percentages of those who conserved electric current increased (Azaiza et al., 2006). The use of electric argumentation increased regarding all the questionnaire problems. Concepts that appeared rarely in the younger ages were used extensively by pupils aged 11 - 12: closed circuit, current, electrical charges and conductors ("the cloud is an electrical conductor"), together with better distinctions between conductor and insulator (Azaiza et al., 2006). The idea of separation of electrical charges is manifested by 11 - 12 pupils, in the explanations of thunder and lightning and electrostatic experiments. But pupils still speak about empting of charges, causing electricity or spark (similar to "the battery is empty", Lee 2007). Human body show mainly the same features except of moving to descriptive after first instruction.

This research was conducted with a relatively a small group of pupils, therefore it is difficult to generalize its results and conclusions. Some support can be derived from the research of Azaiza et al. (2006), research on populations of fourth graders (age 9), of pupils coming from different background of the same Muslim religion. The previous research was aimed at comparing the pupils' concepts in three different groups, and the influence of the background on each of them. The aim of this research however, was to follow the change in the explanations, through the duration of three years, using qualitative descriptions. This aim justified the inclusion of complicated natural phenomena, which were not fully understood at this stage. Our interest was in the conceptions of the pupils and their change. Some conceptions that appeared mainly before instruction were typical to the traditional background of the pupils, further instruction showed how pupils made a compromise between the use of traditional beliefs and the learned physical explanation (research question 3).

# Implications and Suggestions

Surveying the previous research in detail, pointed at the definition of the battery, as a source as creating mist-conceptions: Current was not conserved, and the insulator was miss-understood. The following suggestion may give an answer to these problems. Instruction at the elementary school level: the results observed here among the sixth graders, and results of previous research; emphasized the importance of introducing electrostatics experiences, in elementary school. We will give some reasons to motivate such a conclusion: electrical current had only been a known fact since eighteen century (Wolf, 1961), while electrostatics phenomena were known since the ancients Greeks, and the word "electron" was connected to observations made by the Greeks. Giving examples of electrostatic phenomena connected instruction to the history of electricity (Wolf, 1961). Electrostatic interactions are related to the explanation of natural phenomena, such as thunder and lightning and other. Electrostatic ideas connected to the explanations of natural phenomena, preceded later instruction such as the structure of the atom (Shen & Linn, 2010). Recent research shows that electrostatics experiences are needed to overcome the misconception of asymmetry between conductors and insulators (Galili & Bar, 2008; Guisasola, 2008). And above all, it seems as though knowledge of electrostatic could be used to explain the battery, and its role in separating charges: one kind of charge concentrated at one edge of the battery and the other at the other edge. This difference in the density of the charges created the force that moved the electricity through the circuit. A similar idea was used by Başer & Geban (2007) regarding condensers: "The condenser does not store charges but rather, there is a separation of charges within it". This replacement of the definition of the battery will prevent the need to use energy explanations that, as literature showed, are not accepted at the elementary school level and even later. This will also replace the source concept, and reduce misconceptions referred to by Neidderer & Goldberg (1987), Reif & Larkin (1992) and Lee (2007). Separation of charges created force between the contacts, connecting the batteries' sides through a conductor moved the electricity charges already existing in the conductor, according to its resistance. These ideas may not be fully accepted at the fourth grade, (age 9), but will be gradually applicable starting from the sixth grade and towards higher levels of instruction. Some ideas about separation of charges were already suggested by 11 - 12 years old pupils concerning electrostatic experiences. This result shows the importance of introducing electrostatics phenomena as the base of understanding and using electricity.

We should explain the need for two exposures to instruction. The findings show that most of the development occurs between the end of fourth grade and beginning of sixth grade. The question is therefore, is instruction in fourth grade really needed, seeing as it did not contribute to the increase in electrical causal explanations? Our answer is that the concepts learned at a young age need to be internalized by the pupils; a process that occurs after the first instruction, and helped by explanations given in human body weather domains. This internalization together with the maturity that contributes to the general increase in causal explanations is found in the development observed at the beginning of sixth grade. Another benefit of the first stage of instruction is increased motivation (Chambers & Andre, 1997) in both male and female pupils, achieving similar results. Pupils became more open to the ideas; there was a noted increase in their ability to benefit from secondary sources of knowledge, such as the TV (i.e. National Geographic), and in the assimilation of new concepts from them. As for bridging the gap between traditional beliefs and scientific facts was to give the explanations as we see them, and allowing the pupils to keep their reference to God as an initial source that activated phenomena. Difficulties observed regarding the acceptance of causal thinking at the end of fourth grade was overcome towards age 11.

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