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LEARNING ELECTRICITY IN ELEMENTARY SCHOOL

ABSTRACT. The study investigated elementary school pupils' ideas concerning the concept of electricity and the effect of school instruction on the pupil's views. Pupils of different cultural backgrounds were assessed to ascertain their knowledge in four areas: Relation of certain natural phenomena to electricity; Mental models (images) of direct current in a circuit; Images possessed regarding electricity and electric current. Pupils' ideas were investigated before and after instruction, thus providing information about the effect of instruction on the views of pupils. In construct to the previous findings, certain phenomena (lightning and thunder among them) were related by the pupils to electricity even before those were taught. Evidently, the instruction changed the mental models and images of electricity and electric current.

KEY WORDS: introductory instruction, mental models, direct current, scheme-of-knowledge, cultural background

Electricity is introduced as a subject of teaching at the fourth grade of elementary school. The topic is presented in a very descriptive and concrete form at this stage. The educator's aspiration is 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, (3) introduces the fundamental notions of circuit, battery, current, electricity consumers, even without their precise definitions, and (4) encourages the construction of concepts (mental models) of electricity (such as electricity flow), which albeit being simplified, can serve as a basis for further learning and refinement at higher levels of education.

The present understanding of learning was agreed on to be known as constructivism educational theory (e.g., Tobin, 1993) recognizing the central role of learners' own spontaneous ideas on the subject of instruction (as well as regarding the nature of science and its epistemology). These strongly interact with the presented knowledge and determine the results of the process of learning. Addressing learners' ideas about the topic being taught, thus stipulates success of the process. In this study

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we investigated the ideas of elementary school pupils about electricity and the effect of instruction on them. From a range of possibilities, we chose to examine several aspects which seem to be the most important and informative regarding the knowledge of electricity at this age: (1) images of electricity and electric current, (2) direct current models, (3) pupils' notions about the relationship of electricity to natural phenomena. Pupils' ideas were investigated before and after a particular unit of instruction currently being used in Israel and which used the textbook: *With the current* (Levinger & Dresler, 1993).

Two main reasons that justify the decision to carry out this investigation were: (1) Previous studies did not include 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 dealt with the children of nine years of age (grade four), the age of initial school instruction of electricity.

The major problem of teaching electricity at any instructional level, and especially in elementary school, is the abstract nature of this knowledge and the fact that students observe and try to explain the macroscopic phenomena resulting from some microscopic processes, which are not directly observed or perceived. One could imagine that two bulbs connected in a 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. This lack of direct sense perception, and thus the unavoidable abstract nature of the subject, make the instruction highly challenging. Pupils are required to construct mental images of a complex subject they never observed. The challenge is to find out how to present and explain such fundamental and highly abstract concepts as electrical current, voltage and resistance, which are necessary for the scientific account of the electrical circuits and their observed features. We assume that at the elementary school the concept of voltage is too abstract and should be replaced by the more concrete concept of "source." The concept of resistance should also be explained concretely, such as by comparing with a rough road. Some of the results, which will be described here, will be used to support ideas apt to facilitate the internalization of the concepts by the pupils. The particular form of instruction depends, of course, on the type of population, its age, previous knowledge, etc. Our aim here was to ascertain the concepts used and elicit the explanations employed by pupils aged nine. We wanted to see how they construct their new knowledge using their initial notions regarding relevant subject domains. This would reveal the effects of instruction and the effects of cultural background of the pupils who came from a variety of social and ethnic backgrounds. The findings are expected to provide insights into the way pupils' think, progress in their conceptions, and might suggest differential instructional approaches for various populations.

The pupils investigated by us represented four different groups chosen from the abundance of populations of a highly pluralistic Israeli society. We chose to examine Hebrew-speaking pupils from urban and rural schools, and Arabic-speaking pupils from a small town, and a group from a Bedouin village. All the participants attended schools of the government education system (about 80% of all pupils), which implied eight years of obligatory learning (the elementary school). The young age of the pupils affects the nature of the curriculum, the learning materials as well as the instructional methods. These will be detailed in the discussion section of the paper.

PREVIOUS RESEARCH ON ELEMENTARY STUDENT'S CONCEPTS OF ELECTRICITY

Images of Electricity

There are few studies revealing images of electricity. Some started to examine the knowledge of students aged 12–14. They reported that pupils at this age related electricity to light, fire and potential danger. Some secondary pupils imagine electricity as a multitude of tiny particles, thus creating an image of little charged balls as carriers of electricity moving in wires. This image is popular among pupils of secondary school of and teachers of elementary and secondary schools (Osborne, 1981; Stocklmayer & Treagust, 1996; Borges & Gilbert, 1999). It was documented that pupils very often use inaccurate theoretical concepts to account for the phenomenon of electricity, for example, "voltage gives power to the circuit," "battery gets empty," "current is consumed."

Direct Current Models

Five models accounting for the electric direct current were recorded in special studies (Osborne, 1981; Shipstone, 1984):

1. The one-polar model, in which the electric circuit is not closed (current runs in a wire which connects one pole of a source with the bulb).
2. The clashing current model, in which current flows from the two poles of a source meeting in the resistor (the consumer of electricity).
3. The model of decreasing current running in one direction.

4. The model of shared current among the circuit components (each added component reduces the current by a certain amount).
5. The model of a constant current (determined by the resistance of the circuit and the battery) throughout a closed circuit (the scientific view).

Tiberghien and Delacote (1976) observed primary school children manipulating batteries and bulbs. The researchers found that the children employed the model of electrical current that "flows" due to the battery or some other agent, eventually reaching the bulb. This flow was named by the children "electricity" or "current." Many were not aware of the requirement of the circuit to be closed (used the first of the five mentioned models). Driver, Tiberghien & Guesne (1985) showed that an average of 43% of pupils' aged 11–17 used the clashing currents model (the second model). As will be shown, these ideas are similar to those found in our pre-instructed population of younger children. Observations showed that the meaning of the closed electric circuit was not fully clear even at a much older age (Bensegire & Closset, 1996). Similar to Galili & Bar (1992) in mechanics, Bensegire & Closset (1996) demonstrated that if the electric circuit is portrayed in a somewhat unconventional way (e.g., drawing one source more prominently than the other), the students adhered to the water analogy and abandoned the need for the "closeness" of the circuit (Eylon & Ganiel, 1985). Trials to account for this need were done through the water analogy. However, though the water analogy remains to be a powerful tool of instruction for teachers, at the same time, it possesses a great misleading potential for confusion in young students. The analogy deserves a much more deliberate explanation of its validity to include in the courses for teacher training, but it is rather inappropriate for elementary school pupils.

The relevance of electricity to the explanation of natural phenomena in the views young learners was not checked before.

Cultural Effects

Recently some researches addressed dependence of pupils' achievements in learning sciences on their cultural background. Lower achievements were registered in pupils coming from non-western society as compared with those of pupils coming from western countries (Baker & Taylor, 1995). Ethnically specific views concerning natural phenomena were recorded in Muslim population by Caillot (2002). Their ideas were not connected to electricity. In this study pupils of different cultural backgrounds, Jewish and Arabic, were investigated and compared. This was done in order to find out whether different strategies of instruction should be designed to address various groups of learners, and if so, what specific type of curriculum should be used in each case. As will be detailed further, the results are more complicated than the comparison of achievements between western and non-western societies.

METHODOLOGY

Population and Sample

Five groups of pupils comprised the sample of this investigation.

1. One hundred Hebrew speaking pupils comprised three groups. Group A consisted of 30 grade three pupils from a regular city school. They were probed before instruction on electricity. Group B also included 30 grade four pupils from a regular city school. A and B groups were interviewed after instruction in electricity to determine their models of direct current. The role of these groups in comparison with the other groups will be discussed later in the paper. Group C consisted of 40 grade four pupils from a rural school. These pupils were investigated twice, before and after instruction.

2. Two groups of Arabic speaking pupils: group D consisted of 80 pupils from a small town school (investigated before and after instruction, five of which were subjected also to an oral individual interview). Group E consisted of 40 pupils coming from a rural school of Bedouin origin, investigated before and after instruction.

Groups C, D and E were subjected to a written test (see tools) before and after instruction. Groups D and E were exposed to question 9 of this test also three months after instruction. This phase was defined as the post-post stage. Groups A and B were checked only about their ideas concerning the models of current. The reasons for a certain irregularity of testing will be explained in the section *Results* (subsection *Models of Direct Current*), since the addition of these groups was done in light of the results of the pre- and post-tests of groups C, E, and D. Five pupils of group D were individually interviewed regarding the same test.

Descriptions of the Groups

The groups that took part in investigation were very diverse, and represented the heterogeneous Israeli Society.

Groups A and B. Both these pupils' groups were from a school in Jerusalem. Their background and average achievements were similar to the average of the Hebrew speaking Israeli pupils of their age.

Group C. These pupils who lived in a small village, were of a privileged social and cultural background. Their parents were very keen of educational enrichment, both formal and informal. This point will be elaborated upon while describing the results.

Group D. The pupils of this group came from a small city. These were Arabic speaking pupils with the cultural background reflecting diversity regarding their level of education, and religious tradition more than all other groups of the study.

Group E. The pupils of this group were Arabic from Bedouin origin (Bedouins used to be nomads but now they live in small villages). This population preserved certain cultural differences.

Participants of groups C, D and E came from a small town and two villages of close locations, neighbors, but still preserving differences, which will be detailed while describing the results.

Tools

The questionnaire (see Appendix) contained nine questions addressing three following aspects of electricity: explanations of natural phenomena, images of electricity and models for direct current. These aspects were addressed by open questions.

The natural phenomena to be explained were picked up for the following reasons. *Thunder and lightning* were addressed in the previous research, but connection of this phenomenon to electricity was not indicated. *Phosphorescent fish* and *shy lady* were included as representing biological phenomena, not connected to electricity (it was, however, hypothesized that the pupils may connect these effects of light and motion to electricity). *A comb and hair* and *taking off the cloths* present classical experiments regarding electrostatic phenomena, and the question was whether they would be identified as such. The two next questions addressed the *human nerve system* and *the state of life*. The relation of the latter issues to electricity might be hard to expect in a traditional society. These speculations will be compared to the findings.

Instructional Unit

The instructional unit used for the teaching was *With the current*, which was a regular learning resource in Israeli elementary schools, used in Hebrew or Arabic versions. The unit reflects recognition of importance of electricity in every day life. In order to increase the motivation to learning this domain of science, the unit was written in accord with the STS

(Science, Technology and Society) curricular conception (Levinger & Dresler, 1993) which tries to present scientific ideas as emerging from their technological and social manifestations, not as mere applications of the scientific principles stated. Within this approach pupils are first presented with many uses of electricity, discussing its role in household appliances, street illumination and industry. Safety rules, precautions in the use of electricity are stressed. On the other hand, it might be noted, that the book thoroughly guides the learner in the experience of the electrical circuit, but does not encourage the free exploration. Thus, some specific conditions for the bulb to be lit – such as how the battery poles and the bulb terminals should be connected, comprising a closed circuit – are not specified. Class observations confirmed that the instruction regarding electricity was similar in the groups, but the Hebrew speaking group C was exposed to a course in biology in parallel to the learning about electricity, which affected the post instructed results.

RESULTS

Images of Electricity and Electric Current

Six images were recorded in the responses of our subjects. They were as follows.

Practical. The participants described electricity in general terms, addressing its practical usefulness and effects of appearance: "Electricity helps equipment to function," "Electricity is needed in industry," "Electricity caused the bulb to give light." Stocklmayer and Treagust (1996) reported about the claims corresponding to the practical image of electricity, as provided by practitioners and electrical engineers. Within this approach electrical circuits were mentioned, if at all, as a whole, stressing their practical value. But in spite of this apparent similarity our participants' practical image was different from that of the adults. This is because the useful physical concepts, such as electrical power, field, potential and the design of circuits, generally known to the students in higher grades, were not known to our younger participants, both prior to and after the instruction. The practical view of our participants was simple and straightforward. They just mentioned numerous electrical appliances they observed in their every day life. These young pupils defined electricity as the entity responsible for the functioning of these appliances. The practical view, "electricity is about the bills we pay" (group E) was also mentioned once. Observing Table I we see that the percentages of those who held the practical im-

TABLE I

Electrical images given in the various groups

Images group	Practical	Descriptive dangerous	Current or power	Static electricity	Static magnetism	Unnatural	No answer
C pre	7	7	15	15	0	0	56
C post	22	44	22	0	11	0	1
D pre	30	31	0	0	0	13	26
D post	40	0	15	15	15	0	15
E pre	25	38	0	0	0	20	17
E post	40	10	20	20	0	0	10

age increased, in group C, D and E, after instruction. The practical view was emphasized in the instruction, and consequently the percentages of participants addressing to it raised after instruction.

Danger and the Need for Caution. The following claims of pupils represent another aspect strongly involved with the image of electricity: "Electricity is like fire," "Electricity might cause death," and "It electrifies and causes pain." Solomon et al. (1985) defined these ideas as "a store of life-world knowledge, with associated folklore and emotional overtones." Solomon et al. (1985), Oldham, Black, Solomon & Stuart (1986), Stocklmayer & Treagust (1996), and Borges & Gilbert (1999) found these views among pupils in the early years of high school. They described electricity as a "fire" or a "dangerous animal." Among the pupils we investigated some demonstrated this view before and after instruction (Table I). The textbook stressed safety instructions, and in group C this view of caution increased considerably (most of those pupils did not answer at all before instruction, Table I). In the Arabic groups, however, this response decreased. The difference between the groups may be accounted for by a different stress in the instruction. Or, the dissimilarity could be due to the change of views to manifestations of electrical current, electro- and magneto-static phenomena never observed in groups D and E before the instruction.

Electricity as a Current. An important image of electricity was demonstrated in the claims such as: "electricity flows," "electrical current comes from electricity" and "in touching electricity the current is created." Some of our subjects (group C) mentioned *static* electricity as causing electrical current. Water analogy also appeared in the following relation made:

"electricity is like a flow of black water" (group E). Unlike older and more experienced populations, younger children did not specify the current as "little charged balls" or "electrons." This fact was mentioned since group C was more exposed to informal instruction (books, radio, television), as was apparent from the vocabulary they used (Table II) before instruction. It was thus interesting to find out if they would mention the possibility of electricity as comprised of moving balls. However, they, as the pupils of other groups, didn't. After instruction some of our pupils (group C) addressed the current as flowing "from plus to minus." Borges and Gilbert (1999) reported that even for the older population of students particles image of current lacked details, and rather resembled "the flow" in a general sense. Observing Table I one may see that the image of current increased in group C after instruction. This image did not appear at all in both Arabic groups before instruction, and it was observed in those groups after the instruction.

Electricity as a Magnetic Feature. Interestingly, the young subjects (groups C and D) attributed magnetism to the electrostatic attraction. This image was used to explain natural phenomena: "The threads came closer, they were attracted by the magnet," or, in regarding the *hair and comb* observation: "this is due to the magnetism between them." The same idea was used to define electricity: "electricity is the magnet that attracts." A similar view was recorded among students of a much older age (Stocklmayer & Treagust, 1996). Our observations show the origins of this misconception. Apparently, both the every day language and regular experience do not challenge this thinking. This view was not recorded in group C before instruction but appeared in both C and D groups after it. It did not appear at all in group E.

Electricity as a Static Feature. Some pupils conceived electricity as a static feature that explains natural phenomena. They also described electricity as "charge" that attracts. No more features specifying this "charge" were provided. Notably, we did not record *repulsion* in such descriptions of electricity by young children. In group C this image was observed before instruction but disappeared after it among other electricity images. This image remained, however, among the explanations provided to the natural phenomena. In groups D and E this image was not recorded before instruction and appeared after it.

Electricity as an Unnatural Entity. Several individuals among the Arabic speaking pupils showed this image of electricity before instruction. This view is apparently related to their cultural background, in a way attributing electricity to "God." The pupils also defined electricity as the "soul"

TABLE II

Types of answers exemplified given to explain natural phenomena

The question	Type	Group
	Descriptive and emotional	
Phosphorescent fish	"The fish is colorful"	E
Thunder and lightning	"Lightning is light, thunder is noise"	D
Thunder and lightning	"The lightning makes the sky bright and the thunder make noise"	D
The shy lady (a plant)	"She is very beautiful and shy"	D
The shy lady (a plant)	"It is a crazy thing"	C
	Personified	
Thunder and lightning	"When the clouds quarrel"	D
Noise due to the static electricity	"Mosquitoes make this noise"	E
The shy lady	"It shies from the sun, and not from the moon"	D
The shy lady	"It does not like the sun"	D
Thunder and lightning	"People do them"	E
	Teleological	
Thunder and lightning	"Lightning is needed to bring rain"	D
Thunder and lightning	"Announce the coming spring"	E
Thunder and lightning	"Announce the coming rain"	D
Phosphorescent fish	"They give light"	D
Phosphorescent fish	"Fish have light because it is dark in the sea, and they need to find the way"	C, D
Phosphorescent fish	"To find food"	D, E, C
The shy lady	"Pretending to be ill and not to be picked up"	E
Hitting the leg	"To help us move"	D, C, E
	Causal	
Thunder and lightning	"The wind causes the clouds to collide"	D, C
Thunder and lightning	"Are made when clouds are rubbed against each other"	D
Thunder and lightning	"When clouds are rubbed and static electricity is created"	D, C
Thunder and lightning	"The gathering of electricity caused the thunder and lightning"	C
Thunder and lightning	"Colliding clouds create static electricity"	D, C
Thunder and lightning	"When the clouds get together"	D, E
Phosphorescent fish	"When the fish absorbs the light"	D, E, C
Hitting the leg	"Because the muscles contracted"	D, E

TABLE II

(Continued)

The question	Type	Group
Electricity and life	"The soul is like electricity when electricity leaves the body dies"	D, E
Phosphorescent fish	"When light approaches the fish it swallows the light and becomes illuminated"	E
	Unnatural	
Phosphorescent fish	"God's messenger in the water"	E
The hair and the comb	"To let the hair pray"	E
Living and dying	"God activates electricity and ceases it as wishes"	D, E
Thunder and lightning	"Is a divine phenomenon"	D
Thunder and lightning	"When God is angry with the people"	D, E
Images of electricity	"These are the soul of things"	E

of things, embedded there by God's will or design. This view was not registered at all in the Hebrew-speaking groups. As an electricity image this view was not observed at all after instruction.

In general, after instruction the number of those who did not answer reduced, especially in group C (Tables I and V). Most of the images recorded here for 8–10 years old pupils were previously identified, to various degrees, in pupils of older ages and even adults. As to the origins of these images, some were rooted in the pre-instruction background and spontaneously developed as the knowledge of threats related to electricity. To a certain extent, such views normally reside in adults and are indoctrinated to the children around. The image of electricity as an unnatural entity, observed in the Arabic-speaking groups D and E, was seemingly of the same origin.

Previous research in older participants showed that learning produced pictorial descriptions involving new views of the learner on electricity. These were "little moving balls" and "circuit." Instruction contributes to the development of electricity concept (Stocklmayer & Treagust, 1996; Solomon et al., 1985). However, in our sample, these images were not expressed, even in group C, where pupils had some informal knowledge about electricity (such as "electricity moves from plus to minus," and "electric charge is built up"). The distribution of the images of electricity, identified in the sample before and after instruction is presented in Table I.

At the post-instructed stage a minority of pupils in all groups addressed electricity as electrostatic, magnetic or current related (Table I). Since the instruction stressed the *practical* and *dangerous* images, the increase in the pupils' choice regarding them was not surprising.

The Ways Pupils Relate Natural Phenomena to Electricity

Do pupils use electricity to account for natural phenomena? How do they do this? We inferred the answer from the accounts and types of explanations provided (Table II). Since these explanations were not presented in the instruction, it could be concluded that the pupils already possessed some ideas of electricity concerning natural phenomena. The scientific reasoning of the phenomena was, of course, beyond this knowledge and the elicited explanations and views solely involved intuition, guesses and self-produced ideas. Electricity was not mentioned explicitly in the questions asked, except in question seven. Hence, the investigated pupils initiated the registered associations to electricity.

We classified the provided explanations into the following categories (Piaget, 1929, 1951): *descriptive* (describing the phenomena, instead of explaining them), *personified*, *teleological* (attributing it to certain goals), *causal* (accompanied with a sort of mechanism) and *unnatural* (relating the phenomena to God) (Table II). The answers reflecting pupils' conceptions and their distribution varied from one question to another and from one group to another. Though the classification was taken from Piaget, the very appearance of all these modes of explanations at the *same* age supports Novak's (1977) criticism of Piaget. Causal answers appeared before instruction, and dominated at the post-instruction stage (Table III). Notably, pre-instructed participants have showed familiarity with the term "electricity" and used it in their account of the phenomena (Tables II, III and IV). Explanations of the phenomena will be detailed in the following.

Description of the Views Regarding the Natural Phenomena

1. Thunder and Lightning. Piaget (1929) investigated children's conceptions of this subject and found the following ideas as common. Thunder and lightning (1) occur naturally, (2) are produced by men, (3) are created by God, (4) created when clouds explode, collide or rub each other, (5) announce rain, (6) are made of fire or coming from the sun. The same ideas were recorded in a more recent study (Bar, 1989). Our findings in the present study were similar. Children said: "Thunder and lightning announce the coming of rain," "they are required to lighten the sky," "thunder and lightning are caused by colliding clouds." Like electricity, thunder and lightning cause fear: "I am afraid of lightning, it causes fire" and "lightning

TABLE III

Answers given to explain natural phenomena (%) (percentages do not always add up to 100% since some of the participants did not answer)

Pre- and post-questions		Answers (%) to pre- and post-questions									
		Descriptive		*Personified*		*Teleological*		*Unnatural*		*Causal*	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
C1		22	44	22	11	22	11	0	0	33	33
C2		22	22	0	0	22	22	0	0	33	56
C3		0	0	0	0	18	22	0	0	56	78
C4		0	0	0	0	0	0	0	0	56	78
C5		0	11	11	11	0	0	0	0	56	67
C6		0	0	11	11	22	0	0	0	44	67
C7		0	0	0	0	0	0	0	0	67	78
	Sum	44	77	44	33	84	55	0	0	289	457
	Average	6	11	6	5	12	8	0	0	41	65
D1		25	25	25	19	25	19	13	0	13	38
D2		25	24	0	0	25	19	13	0	25	21
D3		13	13	13	0	13	0	13	0	38	44
D4		13	0	6	0	0	0	6	0	38	59
D5		13	11	19	14	0	0	0	0	38	50
D6		13	46	25	21	25	0	0	0	19	25
D7		25	50	13	0	0	0	19	13	25	13
	Sum	126	169	90	54	88	38	64	13	196	250
	Average	18	24	13	8	13	5	9	2	28	36
E1		13	19	6	0	13	25	25	6	25	38
E2		19	6	6	0	19	56	25	0	13	25
E3		19	0	6	0	19	25	0	0	38	50
E4		13	0	0	0	13	0	9	0	50	88
E5		13	0	25	13	13	0	0	0	19	63
E6		13	0	25	13	13	25	6	0	25	50
E7		13	13	19	0	13	0	13	0	25	50
	Sum	103	38	87	26	103	131	78	6	195	364
	Average	15	5	12	4	15	19	11	1	28	52

TABLE IV

Electrical causation among the entire population (%)

Question group	1	2	3	4	5	6	7	Average
C pre	22	13	42	45	34	15	40	30
C post	23	25	58	70	50	54	70	50
D pre	7	12.5	19	26	27	13	13	17
D post	22	12	18	31	19	15	9	18
E pre	13	6.5	27	30	14	12.5	19	18
E post	25	16	25	47	42	29	30	31
Average pre	14	11	29	34	25	13.5	24	
Average post	23	18	34	49	37	33	36	

can damage homes and stop electricity." In addition to these previously observed views, about a quarter of both the pre and post-instructed participants related lightning to electricity: "lightning is a spark of electricity, creates thunder and lightning" (group C). Piaget did not describe this relationship at the beginning of the 20th century. Some registered views on thunder and lightning were teleological: "thunder and lightning bring rain" or "thunder and lightning announce rain."

2. Phosphorescent Fish. Electricity was stated to cause light, especially when describing the phosphorescent fish: "the electricity in them [fishes] makes them lit." This corresponds to the practical image of electricity. "Electricity causes light, in the bulb." This causal association was minimal in all groups (Table III), at the pre and post instructed stages. Teleological explanations were mentioned defining the purpose of the light: "to see in the dark," "to catch food" (Tables II and III). Teleological views consisted, about a quarter of the answers. Such answers could be anticipated regarding the *phosphorescent fish*: the light is aimed, according to these answers, to help the fish in its survival (Table II). In group C, this kind of answers did not decrease after instruction. Its decrease was small in group D, and it considerably increased, becoming very high in group E, where it fit the identified *practical* trend, typical to this group: "the light is needed to help the fish in its life" (Table II).

3 and 4. Combing the Hair, and *Taking off the Clothes.* Regarding this context electrical discharge was suggested to occur when certain materials are rubbed against each other (the comb and the hair or while pulling off clothes). This explained the sounds heard and the attraction observed (Table IV). Sometimes, the pupils who used static electricity to account for these phenomena used it also to explain thunder and lightning. Some pupils attributed the considered phenomena to magnetism. The numbers of both *causal* and electricity related answers increased after instruction (Tables III and IV).

5. The Shy Lady. The special behavior of the Shy Lady plant was also related to electricity. Sun and heat were mentioned among other possible causes. The behavior of the shy lady hardly provoke *teleological* explanation, the participants, however, gave *personified* explanations to its behavior. The behavior of this delicate plant was described by comparing it to human behavior before and after instruction. *Teleological* answers were provided by group E.

6. Hitting the Leg. The motor reflex of muscular contraction under hitting of the leg was associated with electricity by the pupils of group C, who were taught about the human body in parallel with their instruction in electricity (Table IV, post instructed group C). The pupils of this group used this reasoning much less prior to the instruction (Table IV). Group D preferred the *descriptive* explanation regarding this issue, while a half of group E provided causal explanation.

7. Life Terminates when Electricity Leaves the Body. Participants considered electricity to be a life threat, while, at the same time, saying that electricity resembled the soul. In groups D and E, only a minority, of pre-instructed pupils used this metaphor as a causal account of life. In group D, this view dropped to a mere 9% at the post-instructed stage. One child in group E (Bedouin origin) explained life-electricity relationship as: "it is true ["life terminates when electricity leaves the body"], since when one has a heart attack, he is treated with an electric shock [which returns the electricity to the body]." While Piaget found that children connected the soul with air, our participants related life and soul with electricity. They used this metaphor to address this entity that cannot be observed or felt and was related to flow, fire and light.

As for the distribution of the answers relating the natural phenomena to electricity (Table IV), one may mention that the rate of such explanations regarding classical experiments of static electricity, such as *a comb and hair*, *taking off the cloths*, was higher than in responses to other questions. Pupils mistakenly explained (in high percentages) the shy lady behavior by ascribing its motion to electricity. Concerning the relation between electricity and life, the term *electricity* was mentioned in the question, and the average score was considerable (except group D). In this group percentages were small both prior and especially after instruction (Table IV). The connection to electricity was less pronounced regarding *thunder and lightning*, *phosphorescent fish*, as well as *the nerve reaction of the leg* before the instruction. The rate of relation to electricity regarding the last problem increased significantly after the instruction. This was especially pronounced in group C, apparently inspired by the biology instruction they received. Regarding questions one and two there was a competition between the *causal* and the *teleological* categories. Increased number of students, especially in groups C and E, referred to electricity in explaining natural phenomena at the postinstructed stage (Table IV).

Summarizing, electricity was frequently associated with natural phenomena connected to fire, light, noise, sound and motion (Table IV) even prior to the formal learning. Electricity was associated as an agent (metaphor) of the human soul. These views were not recorded in previous researches and definitely showed a change from Piaget's findings who investigated this issue in 1929. A sample of answers is given in Table II. Quantitative results of Table III show the various modes of response, both prior and after instruction. The rate of *causal* answers increased in groups C, D and E. A significant increase in relating the phenomena to electricity was in groups C and E (Table IV). Using static electricity for *causal* explanations of natural phenomena confirmed the significance of this image of electricity.

Models of Direct Current

The distribution of pupils' answers among the models in the various groups before and after instruction is given in Table V. At the pre-instruction stage, most of our young subjects, elementary school pupils, who were not instructed about particle structure of matter and electrons, used only two out of the five of the above-mentioned models of current. Previous researches found that these two models were observed also in 12–16 year old pupils but in lesser frequency.

The unipolar model appeared among the answers of pre-instructed 8–9 year old pupils in all groups. This model prevailed (90%) in the pre-instructed Arabic speaking population. The children holding this model regarded the battery as a source, and electricity, as a flow from the source to the bulb, causing its being lit. Several investigators detected this model that missed the idea of a closed circuit, among much older participants, even after formal instruction (Osborne, 1981). The instruction caused a

TABLE V

Models of direct current (%)

Model group (age)	Unipolar	Hybrid	Clashing currents	Uni-directional	No answer
A pre (8)	29.5	56	7.5	7	0
B post (9)	0	8	75	17	0
C pre (9)	12.5	18.5	25	0	44
C post (9)	0	12.5	25	62.5	0
D pre (9)	90	0	0	0	10
D post (9)	38	6	50	0	6
D post–post (9)	10	15	25	50	0
E pre (9)	93	0	0	0	7
E post (9)	33	11	23	0	33
E post–post (9)	12.5	12.5	25	25	25

change, and the closed circuit models appeared in the groups. Still, many participants apparently did not internalize the need for the closed circuit, as was evident by the *hybrid model* developed by some. This model, in our case, presented a compromise between the belief in the unipolar model and the instruction of the closed circuit dictum. The model implied a circuit containing two wires and the current only in one of them. Pupils usually showed the current initiating from the geometrical head of the battery. One may see this construct as a compromise: although included a closed circuit it lacked the fundamental feature of the closed current models, the flowing along the whole circuit. This model was not recorded before. Since, according to the previous studies, the older aged pupils held both uni-polar and clashing currents models already in small numbers, the hybrid model in older ages was not discerned.

Post-instructed pupils aged 9 (grade 4) who previously held the unipolar or hybrid view switched to the clashing currents. The latter model fulfilled the requirement of a closed circuit, although still violated current conservation (Table V). This was evident in the behavior of most students in group B and a half of the pupils in group D. A few of the participants in group B and 62.5% of them in group C provided models of unidirectional current (Table V). The latter rate is higher than the average sited by Driver et al. (1985) for older pupils. Some pupil's in group C evidently held the image of electricity, as a current moving from “plus” to “minus” (Table V). For this very reason, being suspicious to whether this high performance really characterized the regular Hebrew-speaking population of forth grade, we added groups A and B, which were expected to be more representative for this population. Indeed, the results obtained in the pre-test of group A and, especially, in the post-test of group B were closer to the average results at this age (Shepardson & Moje, 1999) and confirmed that the performance of group C in the post-test was unusually high.

A few of the pupils in group B showed the use of the unidirectional model with non-decreasing current. Thus the frequency of the unidirectional model changed considerably between the groups (Table V). Instruction influenced the model chosen to account for the current. However the unidirectional model was registered in the Arabic speaking groups of pupils (D and E) only a few months after instruction in the post–post-test (given after some months).

Discussion

Profiles of the Groups and Effect of Instruction

Hebrew-Speaking Rural Group (Group C). Group C was distinct by the use of formal and scientific expressions, such as: "The gathering of electricity caused the thunder and lightning" (Table II). Similar terminology sometimes appeared in group D (Table II) too, but to a much smaller extent (Tables II and IV). The rates of *causal* answers and those related to electricity were higher in C than in the other groups (Tables III and IV). Those rates increased with instruction mainly regarding *the hair and comb* and *taking off the cloths* questions (Tables III and IV). *Thunder and lightening* and *phosphorescent fish* attracted the *teleological* type of explanation. C group wrote: "They announce the rain" or "They bring it" and "Fish use light to seek food."

Hebrew-Speaking Rural Group (Group C). Another feature typical to this group was refraining from answering before instruction (Tables I and V). It changed considerably (Tables I, III and IV), possibly resulting in the increase of the *descriptive* and *causal* explanations. *Unnatural* explanations were not recorded in this group neither before nor after instruction (Tables I and III). Regarding question 6, the *teleological* answers changed into *causal*, which can be attributed to the biology instruction received. Learning about the human body in parallel with the learning of electricity apparently contributed to the high rate, a half, of those who related the phenomena of *nerve reaction* and *life* to electricity.

Arabic-Speaking Town Group (Group D). This group was characterized by its inclination to their traditional culture. Pupils' answers to questions 1, 2, 3, 4 and 7 contributed to the *unnatural* type of explanations given before instruction. The rate of such answers decreased considerably, remaining only concerning question 7. *Causal* answers regarding this question also decreased in favor of *descriptive* answers (a half). When pupils felt that they could not causally relate electricity to *life* they used *descriptive* explanations. Some pupils choose *unnatural* explanations regarding *life,* and only a few related it to electricity, which fit the mentioned background. The rate of the *causal* category increased after instruction, except regarding *life*, mainly addressed by *descriptive* responses (Tables III and IV). The average percentage of electricity related answers hardly increased.

Rural Arabic-Speaking (Bedouin) Group (Group E). This group was characterized by both pragmatic (for example teleological) and original answers quite different from group C (Tables II and III): "Death occurs when electricity leaves the body, since when you have a hearth attack you are treated with electricity," "Electricity is related to bills," "Death occurs when electricity stops, and it is God who stops it." The latter quote reflects how the child compromised between the traditional and scientific views. Another example of creative answer was: "Phosphorescent fish are the delegates of God in the sea." The activeness of this group was generally high: "no answer" rate was smaller than in the other groups (Table I). *Teleological* and *causal* categories increased. The increase of the *teleological* answers was especially addressing questions 1 and 2, where this was suitable. In question 2, *the phosphorescent fish*, more than a half of the answers were *teleological*, and concerning *thunder and lightning* (Tables II and III) a quarter was of this type.

The rate of *causal* explanations, from being similar to that of group D at the pre-instructed stage, almost doubled after instruction (Table III). A quarter of the answers to questions 1 and 2 were of *unnatural* type before the instruction and only a few related *thunder and lightning* to *unnatural* source after instruction (Table III). The rate of relation made to the *unnatural* source of *life* decreased to zero. A relatively high rate of *causal* explanation (a half) addressed this issue, involving some clever explanations compromising between *causal* reasoning and traditional beliefs (Table II). The rate of relating *life* to electricity, close to group D at the pre instructed stage, almost doubled and the share of *personification* category decreased.

In general, in all groups, fewer pupils refrained from answering after instruction (especially in group C) and the share of c*ausal* explanations increased (Table III).

Piaget (1929) regarded personification, the attribution of human feelings to non-living objects, as typical to young children. In our study, answers of this type reduced after instruction. This might be also the effect of learning other science topics during the time between testing. Important to mention, however, is that none of the phenomena presented in the test was addressed in the electricity instruction. In any case, *personification* type of answers reduced in all groups (Table III).

After instruction the *descriptive* explanations were provided when pupils refrained from other responses. While addressing question 1 (group C), the *personification* and *teleological* categories decreased and more *descriptive* answers were collected (Table III). In group D this category replaced some of the views recorded as *unnatural* in the pre-test data, for instance, regarding questions 7, related to *life*. The pupils of this group chose not to explain *life* causally and preferred a mere description (Table III).

Influence of the Background

The research found several typical as well as unique characteristics of the sample groups.

1. Before instruction, the percentage of no-answer by students' in group C (the Hebrew rural group) was the highest, regarding all the aspects (Tables I, III and IV).

2. Pre-instructed pupils of group C, used electrostatic image of electricity and also employed it in the explanations of natural phenomena (Table I). This image of electrostatic electricity remained post to the instruction only in the explanations given to natural phenomena. This is due to the instruction emphasis on the current and its ignoring static electricity. These pupils could not relate between the concepts of charge and current, an effect evident also from previous research (Eylon & Ganiel, 1985).

3. In the Arabic-speaking groups before instruction, the *practical* and *dangerous* images of electricity appeared interwoven with *unnatural* images. The latter disappeared among the electrical images after instruction, being replaced by features of attraction and current that were absent before instruction (Table I). Among the explanations of natural phenomena the number of references to unnatural source decreased after the instruction, although did not disappear. This is an evidence of ethnic influence involving religious motives, relatively strong in this particular environment. After instruction, such explanations as: "thunder and lightning are commanded by God," "they are natural and holy phenomena" (Table II) decreased, as well as unnatural explanations of *life* (groups E and D, Table III). *Practical* knowledge (experience) was evident in the view: "Electricity is like water, since electricity is dangerous next to the water" (group E, Table II).

4. Differences were observed in the distribution of the models given to direct current (Table V). In the Hebrew-speaking groups the unipolar

model disappeared after instruction, and was replaced by clashing and unidirectional models.

In group B distribution of current models was typical to the average Hebrew-speaking school, similarly to the results of Shepardson and Moje (1999) for the same age. In group C, 62.5% of the pupils showed a unidirectional model and only a few retained the clashing current idea. This high rate is unique in young pupils. In contrast, about a third of the Arabic-speaking pupils retained the unipolar model also after instruction (Table V) with a few of them showing the hybrid model (current in one wire connected to the bulb). The rural Arabic (Bedouin) group E started to change its models of current after instruction: 33% used the unipolar model and 23% the one of clashing currents. Among the pupils of the Arabic town school (group D), half of the pupils mentioned closed circuit models when they chose the clashing currents model. Both Arabic-speaking groups considerably improved their current models during a few months after the instruction, without any further treatment at school, as was registered in the post–post-test (Table V).

5. In the post–post-test the frequencies of models for current in the Arabic-speaking groups became similar to those appeared in Hebrew-speaking group B. We may remind that this group was representative of the average Hebrew-speaking population of elementary schools. There was a difference between the two ethnic groups of the sample concerning the concepts and their rate of change. This matched the report of sociologist Marei (1974) about the slowness of changes in the Arabic-speaking society.

6. The two Arabic-speaking groups were different. While the *causal* explanations, and those which related to electricity, increased considerably in the rural group E, the parallel change in group D was smaller. However, group D provided more advanced models of current than group E did both at the post- and post–post-tests.

Matching the Views of Current and Natural Phenomena

In this study several tools were used to evaluate pupils' ideas. Such a method can reliably reveal the images and concepts held by each particular population. For example, it revealed how the person showing the *static electricity* image, used the same concept to account for natural phenomena. This use of various tools proved its significance for each group of the sample. Thus, even when a certain image was missing among the electricity images held by group C, the same image still prevailed in the explanations of natural phenomena in the same group. Evidently, the results from several tools can better inform about the pupils' views concerning the investigated aspects (Shulman, 1986). Pupils' ideas about the electric current were further elucidated through the interviews. In was found that children couldn't account for the need of a closed circuit by *causal* type of explanation, remaining only *declarative*. The pupils stressed the need for an agent to maintain the stream of electricity: the battery as a "mover" (Aristotelian force–motion relationship). Their views, however, did not (and could not) surpass the *flow* image (Borges & Gilbert, 1999).

The difficulty to change the current model held by pupils was seen in the explanations provided to the natural phenomena. Although developed the awareness of the closed circuit constraint they attained to the scientificaly incorrect view of the clashing currents. This conceptual development matches the claim that students often create *hybrid* models in the course of learning, mixing their original views and the newly learned knowledge (Galili, Goldberg & Bendall, 1993; Vosniadou, 1994). Thus, the clashing currents model conformed the need to use both poles of the battery but did not conserve the current. The same model was observed among 13 years old pupils in Israel (Saphady, 2000). Considering young pupils' explanations of natural phenomena one may reveal the origin of the *clashing currents* view. We suggest that this model presents manifestation (a facet) of a wider scheme-of-knowledge (Galili & Hazan, 2000a, 2000b) that interprets a variety of effects within one framework of *collision*. The collected in our study explanations of natural phenomena provided a broad sample of thinking within the *clashing scheme*. One can recognize this in children's thinking that (1) getting objects close together, (2) rubbing each other, or (3) colliding with each other, all cause certain special effects, as seen in the explanations provided to the *hair and comb*, *taking off the cloths* and *thunder and lightning* (Table II). Experience informs children that collisions may be painful and devastating (between the cars). Already in 1929 Piaget found that children attributed *thunder and lightning* to the collisions of clouds. Bar (1989) added rain to this type of understanding. Both views were recorded in this study too. The analogy between colliding cars and clashing currents was also provided by pupils aged 11 (Summers, Kruger & Mant, 1998). Collisions and their effects seemingly present a common sense scheme-of-knowledge, widely employed in the explanations of various phenomena. The variety of explanations obeying this scheme presented the *facets* of the same scheme. The clashing currents model could be regarded as a facet of this inclusive *Collision Scheme*. It seems convincing to the pupils since it brings a sort mechanical picture to make sense of the phenomena.

Another scheme could be also elicited from our data: *Electricity produces light.* This scheme was clearly identified within the claims of pupils categorized as holding *Practical* image of electricity (Table I). Other facets of this scheme were identified in the explanations of natural phenomena. For example, "Electricity caused the fish to glow" (Table II) and "Lightning gives a spark of light" (group C).

The idea of clashing currents causing the light in the bulb ("Currents collide to give light," Table V) could be referred to both previously mentioned schemes. This situation confirms the structure of the "scheme-facets" organization of students' knowledge, in which the same facet could be shared by two different schemes (Galili & Hazan, 2000a, 2000b). This interpretation of explanations shed additional light on pupils' approach in making sense of natural phenomena and electricity.

The fact, that our subjects did not produce the image of "little balls that flow in the wire" to interpret electricity, also perfectly matches the history of physics. In fact, in the spirit of Cartesian philosophy, the concept of electrical fluid of one (Benjamin Franklin) or two (Jean-Antoine Nollet) kinds, dominated the minds of physicists through the 18th century (Gliozzi, 1965). Gradually the moving particles nature of electricity surpassed, first as a theoretical conjecture, and much later, by empirical evidence, by Michael Faraday at the beginning, and by J.J. Thomson towards the end of the 19th century (Taylor, 1941). This certain similarity between the philo- and ontogenesis with regard to the understanding of electrical current may suggest a different approach to teaching of electricity essentially incorporating the history of science (of course, being appropriately elaborated for the elementary school level), similar to the instruction suggested by Galili & Hazan (2000b) for teaching optics to older pupils.

IMPLICATIONS FOR TEACHING

Commonly, comparisons between the western and non-western societies tend to emphasize the lower achievements in science of the non-western society. In this investigation a somewhat different picture emerges. Indeed, it would be an oversimplification to grade our sample groups C, D and E, solely in the terms of better or worse knowledge. They obviously demonstrated various learning behaviors and different advantages and disadvantages. This result is due to the investigation of understanding of several aspects of electricity knowledge within the same study.

Thus, group E (Bedouin origin) excelled in providing original imaginative explanations, which mediated between traditional and scientific views, and in choosing *teleological* explanations when appropriate, e.g., for the *phosphorescent fish*. On the other hand, pupils' teleological explanations regarding *thunder and lightning*, inadequate in science, were influenced by the tradition. Pupils of group D (Arabic urban) rarely connected *life* with electricity, which was natural to their traditional background. At the same time, the models they provided to the direct current were more advanced than those of group E. As for group C (Hebrew rural), they showed more advanced scientific language, but they often refrained from answering questions when they were not sure in the correctness of their knowledge. Although the test a few months after the instruction showed a significant development of groups E and D, the difference remained between all groups indicates the need for differentiation of the instruction required.

The Arabic speaking groups D and E apparently need more of help to encourage and support the young learners towards understanding the nature of science. Sayings like: "God put on and off the electricity as he wills" presents a real challenge to the educators who intend to promote the scientific views in this population. Indeed, the situation is far from being simple when the background to teacher's explanation about thunder and lightning might include the following claim:

> Both the thunder and the angels glorify Him and out of His fear always praise Him. He sends down thunder-bolts to strike whomever He wants, while they are busy arguing about the existence of God. His punishment is stern. (Alqra'n, Alraed, 13, 13)

To find the way avoiding a blunt collision with the tradition in the eyes of young students (a pedagogically inadequate solution, at least) is a great challenge for the modern science education, demanding from the system a lot of tolerance, respect and wisdom, despite of incompatible knowledge contents. One of the ways to cause a progress is to explain the special nature of science through introducing causal explanations and relating natural phenomena to electricity when appropriate. A special emphasis might be put on addressing the activities in producing scientific views: observations, experimenting, making sense, in order to explain nature by means of the causes within the nature itself (natural causes), that is without addressing any other external cause. This is important especially for such populations, as those comprised our groups E and D. Such an instruction should present human seeking for patterns of regularity in natural phenomena, their reproducibility and independence of personality or esoteric cause. The real question is how one can perform this program in such a young age.

In any case, science instruction should more frequently explicitly address electrical current, explain it scientifically (in the sense of content and method of learning about), even in the simplest appropriate way (this presents an issue for a separate study, we do not address here), encouraging the young pupils to change their views on this phenomenon and the models they spontaneously develop.

The Hebrew-speaking pupils of group C, on the other hand, need to be encouraged to be more active in producing explanations, even when they are not sure of their correctness. A new pedagogical strategy should be introduced, resulting of the scrupulous analysis of students' understanding and of various types of possible teachers' explanations. The recommendations produced by experts in science education through such a research effort should be experimentally verified to avoid the inappropriateness for the particular population of young students. Only practice could lead to deciding of adopting some and rejecting other views of science pedagogy.

APPENDIX. QUESTIONNAIRE

Part One. Explanations of natural phenomena.

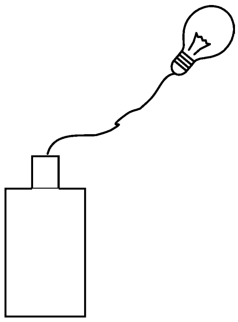
1. How do you explain thunder and lightning?
2. Where do fluorescent fish getting their light?
3. After combing your hair the comb can attract small pieces of paper, how can you explain this finding?
4. Sometimes when you take off your sweater some noises are heard, what is the source of these findings?
5. Why does the shy lady (a certain plant) bend when you put your finger near it?
6. When you hit your leg slightly it comes up, can you explain this?
7. It is said that when somebody dies, the electricity stopped in his body, what is your opinion?

Part Two. Image of electricity.

8. What is the image that comes to your mind when you hear the word electricity?

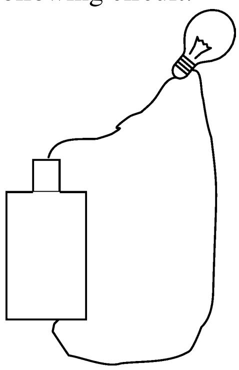
Part Three. Choosing the current model.

9A.



Is there light in the bulb? ___
Explain: ______________

9B. Draw (using arrows) the current in the following circuit:



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