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PRESCHOOL PUPILS MENTAL REPRESENTATIONS ON ELECTRICITY, SIMPLE ELECTRICAL CIRCUIT AND ELECTRICAL APPLIANCES

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Abstract:
This research paper seeks to determine 5-6 years-old pupils' representations about the general characteristics of the elementary electricity, the electrical appliances and their reasoning about the consisting elements of a simple electrical circuit. The sample consisted of 131 children from public kindergarten classes in an urban area in Greece. Data were collected through semi-structured individual interviews. The analysis of the qualitative data showed that although the preschoolers had fruitful representations, the majority of them encountered difficulties on approaching several aspects of the phenomena. Pupils' reasoning about the phenomena also seemed to be without a stable and coherent structure. The need for a categorization of preschoolers' representations based on the use of a system of concrete criteria and the prospect of a didactic approach leading to the creation of a precursor model is designated.

Keywords: pre-school pupils' representations, electricity, early childhood science education

1. Introduction

In the past 20 years, a common research area has been developed within Science Education and Early Childhood Education field, in which the mental representations of children aged 3-8 years are studied for elementary natural phenomena and concepts of

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Physical and Natural Sciences (Kambouri, 2011; Ravanis, 1996; Trundle, 2010). As is well known, mental representations are entities of thought that are shaped in the everyday social and physical environment. These entities are unconscious, focus on their objects, properties and functions, are dominated by certain aspects of situations, and differentiate according to the subject they approach (Ravanis, 2010). A number of researches in different fields of Physical and Natural Sciences have given interesting results for the primary representations of young children. Particularly, in research fields such as biological phenomena (Ergazaki, Zogza, & Grekou, 2009; Miscevic Kadijevic, 2017), thermal phenomena (Kaliampos & Ravanis, 2019), chemical and physical entities (Lorenzo Flores, Sesto Varela, & García-Rodeja, 2018; Vidal Carula & Adbo, 2020), astronomical phenomena (Kampeza & Ravanis, 2012; Skopeliti, Thanopoulou, & Tsagareli, 2018; Jelinek, 2020), sound and optical phenomena (Delserieys, et al., 2018; Pantidos, Herakleioti, & Chachlioutaki, 2017; Theodoraki & Plakitsi, 2013), magnetism (Christidou et al., 2009; Kalogiannakis, Nirgianaki, & Papadakis, 2018), energy (Koliopoulos et al., 2009), meteorological phenomena (Fragkiadaki & Ravanis, 2015; Malleus, Kikas, & Marken, 2017) and the mechanical phenomena (Canedo-Ibarra et al., 2010; Elmalı & Laçin Şimşek, 2020; Hadzigeorgiou, 2002), it was found that the reasoning of young children does not only differ from the Physical and Natural Sciences school knowledge but also holds special facets as it is strongly influenced by pre-logical forms of thinking. Given the fact that in school environment we are interested in transforming mental representations into thought forms compatible with school knowledge, an important phase of the teaching process lies on the detection, recording and classification of those representations. In the present study we tried to approach the mental representations of children aged 5-6 years for elementary electricity.

2. Literature Review

Regarding the understanding of elementary electricity have been made many studies (Koumaras, 1989; Koumaras, Psillos, & Tiberghien, 1989; Métioui, Baulu-MacWillie, & Trudel, 2016; Métioui & Trudel, 2020; Ouasri & Ravanis, 2020), but only a small number of researches have been held with early childhood pupils.

Shipstone (1984) studied the way 8-year-old pupils' approach simple electrical phenomena and found great difficulty in differentiating basic concepts. According to his findings, 8-year-olds pupils had difficulty trying to turn on a light bulb when given a battery and wires. They approach the battery as an active source and the rest of the electrical circuit as a consumer-receiver, although it was not clear in their minds what exactly is consumed.

Fleer (1991) also studied the difficulties faced by pupils aged 3-5 years when deal with the notion of electric current. Pupil's views seem to be shaped by two factors: everyday language that differs from scientific and everyday experience. This highlights the role of teacher who should determine the entry point for pupil exploratory comprehension by examining four factors, namely teaching context, possible alternatives, everyday language and views of children.

Solomonidou and Kakana (2000) studied the way pupils aged 5.5-6.5 years old deal with electricity and the operation of electrical appliances. Their research findings showed that pupils treat electricity as a static entity even though the majority of them are familiar with detecting electrical appliances. Many pupils seem to hold the view that electrical appliances possess a functional entity that is stored inside them and has 'electricity' characteristics. According to their thinking, once we buy an electrical appliance, we also buy electricity at the same time. Still, they do not associate this entity with battery-powered toys or the batteries themselves, perhaps because they do not observe external components, such as cables, to which they attribute the relationship of objects to electricity.

Koliopoulos, Christidou, Symidala and Koutsoumba (2009) asked 5-6 years old pupils to explain the autonomous movement of a toy car which have been supplied with a battery. From the discussion with pupils emerged the possibility to formulate a reasoning of direct correlation on which the battery was recognized as an external-autonomous cause for car movement. Some pupils also recognized the phenomenon of an entity transported from the battery to the car.

In another study (Glauert, 2009) on the representations of 5-6 years old pupils on both simple electrical circuits as well as their actions on creating a circuit, it was found that pupils express a variety of views concerning the required links in an electrical circuit. They also suggest different types of explanations and have different levels of circuit construction capabilities. The relationship between predictions, explanations and actions regarding the circuit elements is not always satisfactory, as it was often noted pupils giving different explanations while manipulating in the same way the elements of the circuit. Finally, research findings showed that pupil's predictions and explanations for the simple electrical circuit are similar to those expressed by older children or even adults.

Kalogiannakis and Lantzaki (2012) found that 4-6 years old pupils can satisfactorily link basic household appliances to electricity, while many pupils use to link electricity with non-electrical appliances such as a faucet or a classic guitar. In addition, pupils face great difficulty indicating the correct wiring of a simple electrical circuit when they are offered alternative images, while they present fragmentary elements in drawing 'electricity'.

Kada and Ravanis (2016) studied the way 5-6 years old pupils go about creating and operating a simple electrical circuit (wires, light bulb, and battery), and how they view the elements that comprise it, particularly the role of the battery. The results of the study showed that pupils have already begun to form representations which link the battery, the light bulb and the wires to electrical functions, and that the majority of pupils are able, with or without help, to successfully create a simple electric circuit. Moreover, their involvement in the process of creating and operating such a circuit leads many pupils not only to a comprehensive viewing of the circuit, but also to the creation of a pre-energy thought-form in which the battery is acknowledged as the distribution source of an entity which is responsible for the luminescence of the light bulb.

The above-mentioned findings enabled us to formulate a series of questions aimed at capturing the mental representations of 5-6 years old pupils on electricity as a broader category of concepts and phenomena, on the description and creation of a simple electrical circuit and on electrical appliances. Thus, we formulated three sub-research questions:

1. Which are the mental representations of pupils on the wider field of electricity?
2. Which are pupil's mental representations on the elements, their connection as well as the operation of a simple electrical circuit?
3. Which are the mental representations of pupils on the operation of electrical appliances?

3. The Methodological Framework

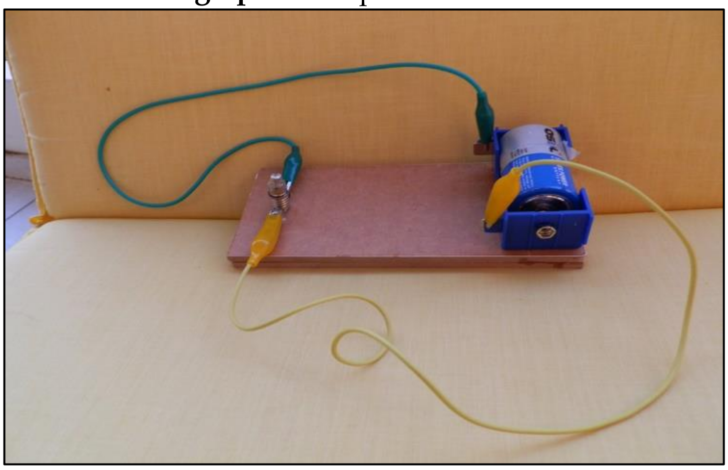
3.1. Sample

The sample of the study consisted of 129 pre-school pupils 5 to 6 years old (64 boys and 67 girls) from eight state kindergarten classes of an urban area in Greece (Patras). None of the children had previously any formal instruction or involvement in discussions or tasks concerning the specific topic. Data were collected through expanded, open type, semi–structured individual interviews between pupils of the sample and one of the researchers.

3.2. Research Procedure and Materials

The individual interviews which were about 20 minutes long, were took place in pupil’s school, in a specifically prepared laboratory space, during free activities. The listing of the data was carried out through sound recordings of the interviews and based on drawings-pictures requested of the pupils. The components used in the research were: connection wires, a battery, a little light bulb and a base on which to assemble all of the above (Photograph 1).

Photograph 1: Simple electrical circuit



3.3. The Interview

The interview developed into three units of questions. Each unit was corresponding to one of the research questions. Starting the discussion, in order to construct a functional framework of communication that guides their thought into the study of electricity that follows, pupils were initially asked: "Today we will play games with what adults call electricity, electric current and electric energy. Have you ever heard those words?" Based on their answers, pupils were instructed to make the most of their experiences. In what follows, we present the structure of the interviews that were carried out.

1) Regarding the first research question, namely the detection of representations on the wider field of electricity, the following questions were posed:
   - 1.1. What are your thoughts when you hear about electricity? Could you please describe it to me in a few words?
   - 1.2. Have you ever heard about electricity? Could you tell me what you know about it?
   - 1.3. Have you ever heard about electrical energy? Could you tell me what have you heard about it?
2) Regarding the second research question, namely the examination of the mental representations on elements, their connection as well as the operation of a simple electrical circuit, the following questions were posed:
   - 2.1. What could you do using these items together?
   - 2.2. What should you do with the battery and cables in order to light up the lamp?
   - 2.3. Could you try to light up the lamp?
3) Finally, for the third research question, concerning pupil's representations on the operation of electrical appliances, the following questions were posed:
   - 3.1. What are electrical appliances?
   - 3.2. Could you tell me three electrical devices?
   - 3.3. How does an electric device work? What does it work with?

4. Results

The processing of data collected from the interviews allowed us to discern a series of alternative parameters or relationships between parameters used by children of that age in order to approaches, describe and explain the electricity different issues. Consequently, we will present three categories of mental representation which were conceptualized based on the data analysis: sufficient, intermediate and insufficient representation. In the "*sufficient*" category are classified the answers to which the references and interpretations-arguments of pupils are compatible with the school knowledge. In the "*intermediate*" category are classified the answers to which pupil's reports are compatible with the school knowledge, however but their argument either does not exist or is weak. The category "*insufficient*" includes the answers to which pupil's reports are incompatible with school knowledge.

For each question that was posed in the interview we present the categories of answers as well as tables with their frequencies.

4.1. 1st Research Question: Which are the mental representations of pupils on the wider field of electricity?

Question 1.1: What are your thoughts when you hear about electricity? Could you please describe it to me in a few words?

In this question, pupils reconstructed their thinking in a way that differs from their daily experience. In sufficient answers were included all those responses that recognized electricity as a separate entity, independent of appliances. To quote pupil 69 "*It's something…. which the refrigerators work with… the televisions*" (P. 69). In intermediate answers were classified those that seem to link electricity with everyday experience. Such is the following pupil's statement "*It is the lamp that lights up…. and the kitchen that works during cooking …*" (P. 31). Finally, insufficient answers were classified as either those indicating ignorance or those related to non-electrical phenomena. For example, as pupil 101 pointed out "*It's in cars… .. when we fill them with oil*".

In the table below we present the frequencies of pupils' answers to question 1.1.

Table 1.1: Answers to question 1.1

Response Category	Frequencies	Percentages %
Sufficient	11	8.5
Intermediate	32	24.5
Insufficient	88	67

Question 1.2: Have you ever heard about electricity? Could you tell me what you know about it?

Here pupil's experiences led to three categories of answers. In sufficient answers were classified those that recognize functions due to electricity. To quote pupil 7, "*It plugs in and makes all the lights come on*". In intermediate answers were also classified responses that make connections to home appliances, with a weak argumentation though. Such is the following example "*As I said before…. the refrigerator…. the kitchen…*' (P. 31). Finally, as insufficient answers were classified the majority of pupils' responses who stated "*I do not know*' as well as some responses that were not related to electricity at all. For example, '*It helps us to see…*" (P. 65).

In the table below we present the frequencies of pupils' answers to question 1.2.

Table 1.2: Answers to question 1.2

Response Category	Frequencies	Percentages %
Sufficient	17	13
Intermediate	27	20.5
Insufficient	87	66.5

Question 1.3: Have you ever heard about electrical energy? Could you tell me what have you heard about it?

The answers here explicitly showed that pupils hold very limited relevant representations. Only one child expressed a sufficient representation that recognized electrical effects: "*It is like something passing and turning on the lights…. which makes them light up*" (P. 109). Answers classified in the intermediate category were consistently showed connections to home appliances. Such an example is the following pupil's statement "*When we turn on fans it is the energy*" (P. 87). Finally, as insufficient answers were classified the vast majority of pupils' responses who either stated "*I do not know*" or pointed out answers that were not related to electricity at all. Such is the following statement "*It is to fill our radiator with oil…*" (P. 129).

In the table below we present the frequencies of the pupils' answers to question 1.3.

Table 1.3: Answers to question 1.3

Response Category	Frequencies	Percentages %
Sufficient	1	0.5
Intermediate	6	4.5
Insufficient	124	95

4.2. 2nd Research Question: Which are pupil's mental representations on the elements, their connection as well as the operation of a simple electrical circuit?

In the second research question we presented to pupils a light bulb, a battery and two cables as well as a support base with positions for all these elements. After recognizing them, we tried through a series of questions to explore how pupil's thinking approaches simple electrical circuit.

Question 2.1: What could you do using these items together?

Here we recorded three levels of answers. In sufficient answers where included pupils responses who suggested a proper connection in order to turn on the light bulb. To quote pupil 4 "*Just connect the cables and the battery…. and so the light comes on*". In intermediate answers were classified those answers that recognize that objects hold a place in electrical connections but do not link them to each other. Such is the following pupil's statement "*the cables are in different ………. on televisions let's say…. the same with the bulbs…*" (P. 130). Finally, as insufficient answers were characterized those were pupils simply stated "*I do not know*".

In the table below we present the frequencies of pupils' answers to question 2.1.

Table 2.1 : Answers to question 2.1

Response Category	Frequencies	Percentages %
Sufficient	75	57
Intermediate	32	24.5
Insufficient	24	18.5

Question 2.2: What should you do with the battery and cables in order to light up the lamp?

In sufficient answers were categorized responses that suggested to connect both cables and battery to the base. Such an example is the following pupil's statement "*I will put the two cables here and the battery here…. and then the lamp will light up*" (P. 55). As intermediate answers were classified those that referred to the battery and / or the cables without suggesting however a specific connection. This is well reflected in the following pupil's statement "*With cables… if we put them together…*" (P. 130). Finally, as insufficient answers were characterized those were pupils pointed out "*I do not know*".

In the table below we present the frequencies of pupils' answers to question 2.2.

Table 2.2: Answers to question 2.2

Response Category	Frequencies	Percentages %
Sufficient	91	69.5
Intermediate	24	18.5
Insufficient	16	12

Question 2.3: Could you try to light up the lamp?

In sufficient answers were classified pupils' responses who tried to connect the battery and the cables to the base. Sometimes they do it without help, while other times we support those pupils who face technical difficulties in making the connection. Here belongs the following statement "*as I told you, if we connect the cables and the battery correctly then the lamp will light up*" (P. 55). In intermediate responses included pupils who tried to connect the battery and cables, even though they did not manage to make it correct. When they were ready to give up their efforts, we helped them to make the connections correctly so that the lamp would light up. An indicative answer is "*Okay, now the lamp lights up… We had to connect the green cable here*" (P. 98). In insufficient answers were classified responses were pupils stated "*I do not know*". We proposed these children to manipulate the materials so that the light bulb lights up. By so doing they had the chance to watch the correct connection and continue after this the interview.

In the table below we present the frequencies of pupils' answers to question 2.3.

Table 2.3: Answers to question 2.3

Response Category	Frequencies	Percentages %
Sufficient	99	75.5
Intermediate	22	17
Insufficient	10	7.5

Question 2.4: Could you tell me why did the lamp light up?

With this question we tried to find out whether pupils recognize any unifying entity for the operation of the circuit beyond its components, such as electricity. Indeed, in sufficient answers a representation emerges that attributes the operation of circuit to current. An indicative answer is "*Because when the lamp was lit, electricity was passing…*

from everywhere… the cables… everywhere" (P. 120). In intermediate answers pupils' argumentation was based on the correct connection of circuit elements. To quote pupil 77 "*the lamp light up because we connect them correct…. If the wire came out of the hole, it would not light up…*". As insufficient answers were characterized those responses were pupils either stated "*I do not know*" or did not answer at all.

In the table below we present the frequencies of pupils' answers to question 2.4.

Table 2.4: Answers to question 2.4

Response Category	**Frequencies**	**Percentages %**
Sufficient	42	32
Intermediate	75	57
Insufficient	14	11

Question 2.5: We saw before that the lamp lights up. Do you believe that the battery plays any role in this?

Taking into account that the role of battery is conceptually important in understanding elementary electricity, we decided to insist on this issue. Sufficient answers highlight a representation of pupils that assigns to the battery a "reservoir" role of an entity that supplies the circuit and is expressed in different terms, such as "energy", "current' or "something". An indicative answer is the following "*the battery contains something that goes in the cables… and everywhere… and helps the lamp to light up*" (P. 41). Intermediate answers included responses that vaguely talked about the battery without making any connection to the circuit. The following two statements reflect this category "*the battery has the current…*" (P. 39) and "*the battery gives light*" (P. 72). As insufficient answers were characterized those responses were pupils either stated "*I do not know*" or did not answer at all.

In the table below we present the frequencies of the children's answers to question 2.5.

Table 2.5: Answers to question 2.5

Response Category	**Frequencies**	**Percentages %**
Sufficient	40	30.5
Intermediate	75	57
Insufficient	16	12,5

4.3. 3rd Research Question: Which are the mental representations of pupils on the operation of electrical appliances?

Question 3.1: What are electrical appliances?

With this question there was made an attempt to determine whether pupils, based on the common feature of electrical connection, classify to a single category devices with different daily usage. Among sufficient answers were classified responses were pupils mainly referred to the common electrical character of these devices. Indicative is the following answer *"It is what we put in the socket… kitchens, refrigerators…"* (P. 4). Intermediate answers included responses that vaguely talked about a particular device. Such is the following answer *"the vacuum cleaner that we clean the floor…"* (P. 88). As insufficient answers were characterized those responses were pupils either stated *"I do not know"* or did not answer at all.

In the table below we present the frequencies of pupils' answers to question 3.1.

Table 3.1: Answers to question 3.1

Response Category	Frequencies	Percentages %
Sufficient	22	17
Intermediate	34	26
Insufficient	75	57

Question 3.2: Could you tell me three electrical devices?

With this question we tried to find out whether pupils had formed a single category of devices in their thinking. Among sufficient answers were classified those in which pupils easily chose three electrical appliances. An indicative pupils' answer is the following *"yes, the electric stove, the hair dryer and the electric car that we will buy..."* (P. 92). In intermediate answers were categorized those answers in which pupils found it difficult to point out three devices. Typical answer is the following *"let's say a light bulb…. maybe an electric phone?"* (p. 111). As insufficient answers were characterized those responses were pupils either stated *"I do not know"* or did not answer at all.

In the table below we present the frequencies of pupils' answers to question 3.2.

Table 3.2: Answers to question 3.2

Response Category	Frequencies	Percentages %
Sufficient	19	14.5
Intermediate	46	35
Insufficient	66	50.5

Question 3.3: How does an electric device work? What does it work with?

With this question we tried to explore how pupils construct electrical appliances in their thinking, based on the device choices they made in the previous questions. So, we asked them to tell us the way in which the device they recognized as electric does work. As sufficient answers were classified those responses were the operation of the device was linked to elements that refer to electricity. To quote pupil 92 *"with the socket… we put it in the socket, and it can light up ..."*. In intermediate answers were classified responses in which there was made no direct link with electricity but mainly with the functions of the devices. Indicative is the following statement *"the kitchen? With the heat… it burns a lot when we turn it on"* (P. 102). As insufficient answers were characterized those responses were pupils either stated *"I do not know"* or did not answer at all.

In the table below we present the frequencies of pupils' answers to question 3.3.

Table 3.3: Answers to question 3.3

Response Category	Frequencies	Percentages %
Sufficient	34	26
Intermediate	42	32
Insufficient	55	42

5. Discussion

In the current research we tried to explore mental representations of 5-6 years old pupils on electricity as a broader learning field. Particularly, we investigated their ideas regarding the elements, their connection and the operation of a simple electrical circuit as well as the operation of electrical appliances. In general, the results showed that pupils face significant difficulties in approaching the field of electrical phenomena. However, it seems that their daily experiences led some children to an early mental construction with satisfactory characteristics.

In the first research question terms such as 'electricity' or 'electric current' seem to not be related to anything special for 6-7 / 10 pupils. Instead 2-3 / 10 pupils associated these terms with household appliances or daily activity. Of particular interest seems to be the thought of 1/10 pupils who have already formed in their minds electricity or electric current as an entity that cause specific electrical effects such as lighting or operation of appliances. This finding highlights the possibility of young children thinking to form an abstract mental entity about electricity. In addition, interesting is the fact that the term electricity seems to be far from the experiences of pupils who participated in the research.

In the second research question, we studied the ability of pupils to work with a simple electrical circuit; that is, to explore their ability to operate and combine its basic elements. It seems that this framework was much more favorable to record pupil's mental representations as about 6-7 / 10 pupils described and handled the battery, the two cables and the lamp satisfactorily to achieve the operation of the circuit. The specific nature of this activity also allowed pupils to assign a special role to the battery in the circuit as it was recognized as the 'reservoir' of an entity that leads to the lighting of the lamp (Shipstone, 1984). The fact that this point of view was expressed by 3/10 is rather important for approaching the basic concepts of electricity and should be undoubtedly an important teaching goal for older children. It is also in line with findings of the relevant literature (Kada & Ravanis, 2016).

In the third research question we investigated pupil's mental representations on everyday electrical appliances. As shown by the research data, 2/10 pupils were able to distinguish these devices in a correct manner while also attributing their function to what they recognize as electricity. This is also a finding compatible with the data of the relevant literature (Kalogiannakis & Lantzaki, 2012).

In general, our results highlight the obstacles in pupils thinking for a systematic approach to the basic concepts and phenomena of electricity. Nevertheless, these obstacles should be expected, as the field of learning electricity presupposes abstract possibilities that at the age of 5-6 years are not conquests of thought but objects of elaboration through specialized teaching procedures and cognitive constructions.

However, it is important that some pupils seem to be able to approach simple electrical phenomena using satisfactory reasoning even before any kind of participation in organized cycle of teaching activities. In fact, it seems that certain elements of pupil's thinking form a nucleus for the construction of a precursor model; that is, cognitive entities whose characteristics are compatible with those of school knowledge (Ravanis, 2020). This finding has special significance in setting the didactic goals as it allows the elaboration of activities that could lead from the pre-logical to the logical approach of simple electrical phenomena. Undoubtedly, it would be quite interesting to move toward this direction both the relevant research as well as the development of programs (Charles, 2020) and educational materials (Ravanis, 2017) for pupils of Early Childhood Education.

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