Constructing qualitative energy concepts in a formal educational context with 6-7 year old students

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Abstract

The research presented in this paper is a preliminary empirical study of primary school children's ability to construct a qualitative explanatory model for the 'energy' concept. The research results are particularly encouraging since it seems that 6-7 year old children are able, following a relevant teaching intervention, to utilize a linear causal reasoning and construct a preliminary energy model. Through the use of this model, the children are able to describe natural phenomena, such as the lighting of a lamp or the movement of a small motor using a battery or a photovoltaic cell.

Keywords

Energy, linear causal reasoning, precursor model, primary school

Résumé

La recherche présentée ici est une étude empirique préliminaire de la capacité des enfants de l'école primaire de construire un modèle qualitatif explicatif concernant le concept d'énergie. Les résultats de la recherche sont particulièrement encourageants *car il semble que les enfants âgés de 6-7 ans sont en mesure, à la suite d'une intervention didactique pertinente, d'utiliser un raisonnement linéaire causal et de construire un modèle énergétique préliminaire. Grâce à l'utilisation de ce modèle, les enfants sont capables de décrire des phénomènes naturels, tels que l'éclairage d'une lampe ou le mouvement d'un petit moteur utilisant une pile ou une cellule photovoltaïque.*

Mots Clés

Énergie, raisonnement linéaire causal, modèle précurseur, école primaire

Introduction

The teaching of the 'energy' concept to young students

The research field of the Didactics of Natural Sciences has dealt with the energy teaching across the different levels of education since its formation as an autonomous academic field. This research interest is the result of the reaction of the educational systems of the western industrialized nations to the oil crises and generally to the energy crisis which was affecting them in the beginning of the 70s (Wenham, 1984; Kirwan, 1987). The questions raised by the researchers are related to the mental representations that students form regarding the 'energy' concept and the possibility of developing innovative teaching interventions. These will eventually lead both to the advancement of students' knowledge and to the development of suitable attitudes relative to the social uses of the concept (energy conservation, etc.).

Some of the research questions which were explicitly stated or implied during the most productive research period, in other words during the 80s, (Strickland et al, 1983; Bliss & Ogborn, 1985; Driver & Millar, 1986; Koliopoulos & Tiberghien, 1986; Duit, 1987; Solomon, 1992) are the following: «How do students conceive energy?», «What is the nature and characteristics of the transformation that the scientific concept must undergo in order to become a subject of teaching?», «Is there one or more conceptual frames and/or social practices of reference which will ensure functional and productive educational frames for the concept?», «Is it possible to teach the 'energy' concept in preschool and primary school?»

Over the past years, the energy teaching continues to constitute an important research subject, not only because the effects of the contemporary energy crisis are getting more prominent and the educational systems are required once again to deal with the situation, but also because the research questions raised in the 80s continue to engage researchers (Lemeignan & Weil-Barais, 1994; Devi et al., 1996; Hayhurst, Campbell & Howlett, 1997; Millar, 2005; Domenech et al., 2007). We believe that one of the research questions which has not been adequately addressed is the possibility of developing programs on the energy teaching for preschool and primary school. Even though there are several similar programs (i.e. Intelligent Energy, 2009), the issue that has not been sufficiently addressed so far is if, and in which way, preschool and primary school children understand the energy concept and if they are able to construct descriptive energy models, given the difficulties that arise from its abstract and quantitative nature.

The purpose of this paper is to describe a preliminary, empirical study of primary school children's ability to construct a qualitative model for the 'energy' concept. With this model the children will describe various phenomenological situations, such as the lighting of a bulb or the movement of a small motor using a battery or a photovoltaic cell. This research tested the hypothesis according to which students of early school age are able to construct after a relevant teaching intervention a qualitative energy model utilizing a linear causal reasoning. According to this type of reasoning, students, in their attempt to describe and explain the function of various systems, spontaneously recognize a mediator (which they call power, electricity, heat or energy based on the phenomenological characteristics of the physical system) which acts or is transferred from one object, recognized as the agent that produces an action, to another object of the system, recognized as the patient that receives the action (Anderson, 1986; Viennot, 1993; Tiberghien, 2004).

This paper describes the advantages of the qualitative energy model and the characteristics of the teaching intervention. Furthermore, it presents the results of a pre-test and a post-test given to the 6-7 year old children which demonstrate the students' advancement of knowledge and which reinforce the above mentioned hypothesis. Finally, this paper provides suggestions for further research.

A qualitative explanatory model for the 'energy' concept: The 'energy chain' model

The conceptual frame referred to as the *energy chain* model has been applied both internationally and in Greece mainly at middle school. The conceptual frame has not been expressed uniformly, but nevertheless has some basic characteristics such as:

– It is based on a structure which includes the storage, transfer, transformation, measure, conservation and degradation as basic properties of energy. In reality it constitutes a type of didactical transposition (Chevallard, 1985; 2007) of the scientific knowledge to its school version, which is mainly linked to:

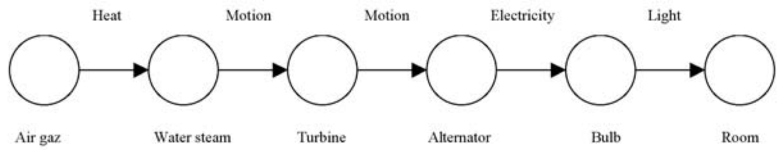
1. the rich tradition of energy synthesis and emergence of the principle of energy conservation that occured during the 19th century (Kuhn, 1977) and
2. the conceptual frame of macroscopic Thermodynamics as it is shaped within the frame of the contemporary science of Thermodynamics (Dodé, 1965; Zemansky & Dittman, 1987). In other words, this model is the most epistemological valid transformation of the scientific knowledge to its school version. The association

of the energy chain model with the historical tradition of the birth of the energy concept allows the expression of its qualitative characteristics, which are necessary when teaching young children. In addition, the correlation of the energy chain model with the macroscopic Thermodynamics lends the concept a conceptual autonomy and cancels the obligatory in traditional teaching correlation of the concept with the abstract and mathematical concept of work.

– The conceptual frame can assume various qualitative and semi-quantitative representative forms, such as the representations of the *function* and *distribution* (Lemeignan & Weil-Barais, 1994), the energy flow diagrams (Falk, Hermann & Schmid, 1983; Viglietta, 1990) or the energy chains which stress the difference between the stored and transferred energy forms (Tiberghien & Megalakaki, 1995; Devi et al., 1996). Figure 1 shows a qualitative energy chain representation of lighting a bulb using a Bunsen burner (Lemeignan & Weil-Barais, 1994).

Figure 1

Schematic representation of a qualitative explanation of the lighting of a bulb using a Bunsen burner (Lemeignan & Weil-Barais, 1994)



As stated in the introduction, the internal structure of the energy chain conceptual model is compatible with the linear causal reasoning. According to Halbwachs (1971), this natural causal explanation is the preferred way of representing the physical world to children. It has been observed that when this type of reasoning is activated by students from the higher levels of primary or secondary school asked to describe and explain simple electrical, thermal and mechanical phenomena, they are able to construct qualitative or semi-quantitative energy concepts (Lemeignan & Weil-Barais, 1994; Tiberghien & Megalakaki, 1995; Koliopoulos & Ravanis, 2001).

Recent research conducted by the Department of Educational Sciences and Early Childhood Education of the University of Patras shows that preschool children give a physical explanation (and not a teleological explanation which was anticipated) based on a pre-energy mental representation which allows them to describe the macroscopic function of various physical systems (battery-car, compressed spring-car, battery-light bulb, battery-motor) (Koliopoulos et al., 2009; Kontogiannatou, 2009). To be more specific, it has been observed that many children are capable of describing the previously mentioned systems either as object chains in terms of their *function* (i.e. the car movement is due to the battery, the lighting of the bulb is due to the battery) or as object chains in terms of *distribution* (transfer of an action) (i.e. the battery gives electricity to the car and it moves, the battery gives power to the light bulb and it shines) (Lemeignan & Weil-Barais, 1994).

Therefore, it seems that we can legitimately post the hypothesis that the compatibility of the energy chain model with the linear causal reasoning is possible to contribute to the construction of mental representations which constitute precursors energy models, even by children of very young age. This knowledge could later form the basis for additional knowledge through the gradual construction of quantitative energy concepts.

– The conceptual frame constitutes a conceptual model which can contribute to a closer connection of the conceptual component with the cultural component of the scientific knowledge (Koliopoulos & Ravanis, 2000). This connection can easily be accomplished if the everyday and the technological environment constitute a guiding principle for the teaching activities. Issues, such as renewable energy sources, conservation of energy, energy efficiency and environmental pollution, lead to the utilization of the energy chain model since it offers the maximum compatibility with the study of these issues.

Method

Research context and participants

The research was conducted with a total of 105 first grade students from a private Primary school in the city of Athens. The 6-7 years old students were divided into four different classes. The teaching intervention was conducted by the researcher, while the teacher of each class was present. The students worked in 52 groups (51 pairs and 1 three-member group) throughout the teaching intervention. The composition of the groups remained the same throughout the teaching intervention. Table 1 presents the classes, the number of students and the number of pairs.

Table 1

Number of classes, students and groups which participated in the research

Classes	Number of students	Number of groups
T1	27 (*)	13
T2	26	13
T3	26	13
T4	26	13
Total	105	52

(*) One of the groups was composed of 3 students.

Teaching intervention

The conceptual aim of the teaching intervention was that students construct a qualitative pre energy model with which they would be able to represent physical situations as object chains, first in terms of their function and later in terms of distribution[1].

The teaching intervention consisted of five units and the duration of each unit was 45 minutes. The intervention was completed within a two week period. The second and fifth units were used also as assessment units. The children worked in pairs throughout the entire intervention. The following part of the paper describes the aim and content of the intervention's teaching activities, the conceptual frame to be built by the students and the anticipated cognitive progress.

1st unit

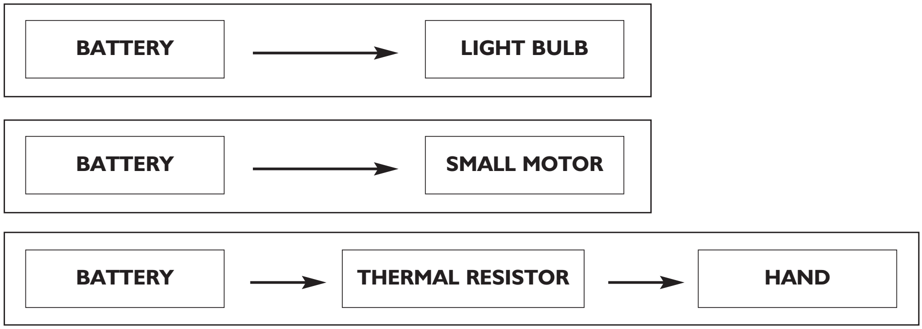
During the first unit students familiarized themselves with the experimental devices and were asked to connect them in order to observe the function of three simple electrical circuits: a battery and a light bulb (system 1), a battery and a small motor (system 2) and a battery and a thermal resistor (system 3). After students correctly connected the devices with or without the help of the researcher, they were asked to describe what they did in order for the three physical systems to operate and to describe the results of the system's function (lighting of a bulb, movement of a small motor, warmth of a thermal resistor).

2nd unit

In the beginning of the second unit the researcher presented the three physical systems the students worked with in the previous unit and set them in function. Each group was then given a set of cards for each system with the names of the experimental devices and cards with the sign of an arrow. The groups were asked to put the cards «in the correct order» and to justify their answer. Figure 2 shows the anticipated childrens' representations of each physical system.

1 Another research target, relevant to the cultural dimension of the scientific knowledge, was that children at the end of the teaching intervention would be able to recognize household systems of production and utilization of electrical energy (i.e. household photovoltaic systems, electrical hotplates) and give a functional definition of the concept of the renewable energy sources (mainly of the sun's energy). This paper neither describes the activities that refer to the cultural dimension of the scientific knowledge nor its evaluation results. We simply note that the connection of the conceptual component with the cultural component of the specific scientific knowledge comprises an equally critical element for the construction of a qualitative energy model (for example, through this connection it is possible to introduce the term 'energy' so it acquires a specific content for the children).

FIGURE 2



Schematic representations the children are anticipated to construct during the 2nd unit of the teaching intervention (pre-test)

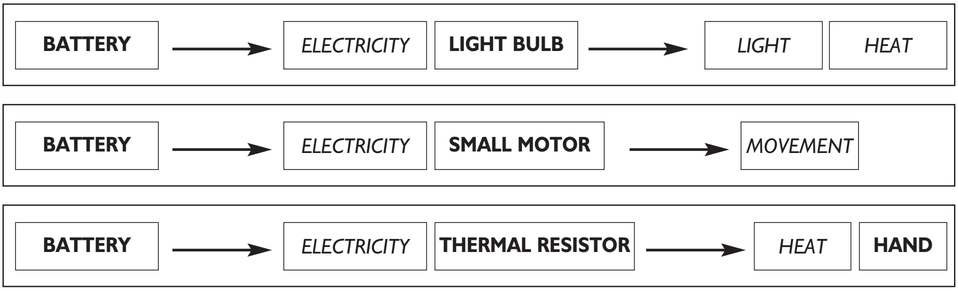
It was expected that these activities would again activate the students' linear causal reasoning so that the children would place the cards in a logical order and obtain object chains with clear causes and results. The basic cognitive assumption for these two units was that the majority of the groups would activate the linear causal reasoning and would describe the three systems as object chains. To be more specific, it was expected that the battery would be regarded as the cause for the function of the light bulb (system 1) and the small motor (system 2) and for the warmth of the hand by the thermal resistor (system 3). The 2nd unit was used as an assessment unit (pre-test).

3rd unit

The researcher began the third unit by reminding the students the activities of the two previous units and by leading them through a discussion to accept the «correct order» of the cards distributed in the second unit. Then the researcher introduced a 'formalized' representation of the chain model by adding the cards 'electricity', 'light', 'movement' and 'heat'. These cards, placed underneath or next to the cards with the arrows, transferred the action of an object –agent on an object– patient. Figure 3 shows the 'formalized' representations[2] introduced by the researcher for each system. It was expected that the discussion with the students during this unit would lead to an advanced representation of the object chains (from object chains in terms of function to object chains in terms of distribution).

2 This is the final form of representations which was reached during the teaching intervention in cooperation with the students. The characteristics of the changes on the teaching content and how these changes arose during the teaching intervention are very interesting topics, but nevertheless are not part of this paper.

Figure 3

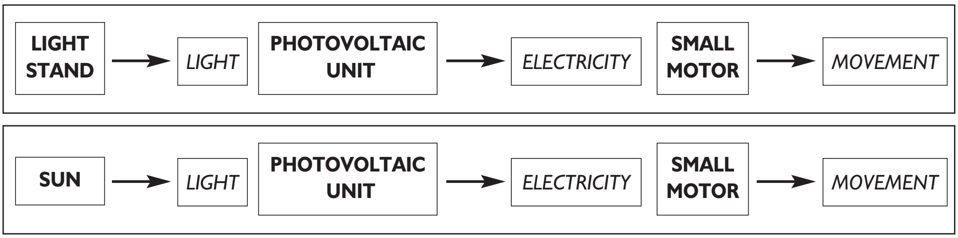


Schematic representations the children are anticipated to construct during the 3rd unit of the teaching intervention

4th unit

The researcher reminded the students the function of the physical system ‘battery – small motor’ and discussed with them its representation with the energy chain model. The researcher then announced that besides the battery there are other devices with which a small motor can operate, such as the photovoltaic cell. The children constructed the simple electrical circuit ‘photovoltaic cell – small motor’ and activated it with the assistance of a small light stand. The students were also asked to think of a way to substitute the light stand and afterwards to compare the sun to the light stand. Finally, the groups were asked to construct the energy representation of the physical system. Through a discussion the following representations were anticipated to be made by the students (Figure 4).

Figure 4

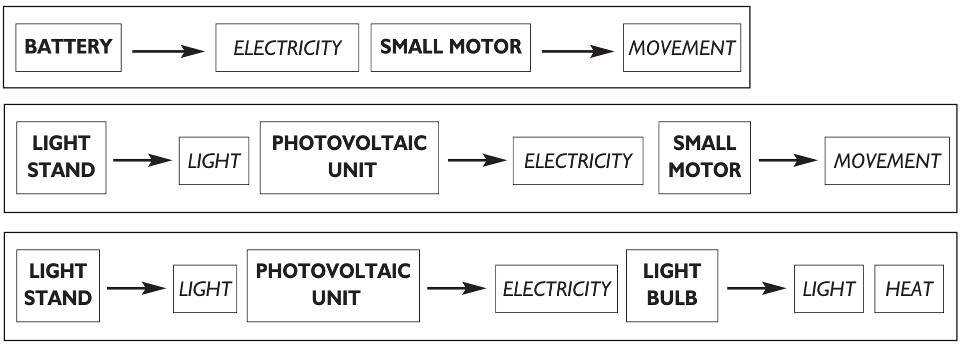


Schematic representations the children are anticipated to construct during the 4th unit of the teaching intervention

It was anticipated that during this unit the students would activate not only their linear causal reasoning but also an analogical reasoning in order to represent a new phenomenological situation as object chains in terms of distribution. In this new situation the object – agent 'battery' was substituted by the 'light stand' and a new device, the photovoltaic cell, was introduced as an 'action transformator'.

5th unit
Initially, the students were asked to connect the devices in order to operate the three physical systems: a battery and a small motor (system 1), a photovoltaic cell and a small motor (system 2) and a photovoltaic cell and a light bulb (system 3). The simple electrical circuits were constructed without any guidance by the researcher. The students were asked to describe their actions in order for the systems to operate (for systems 2 and 3 light stands were provided) and the results of the system's function (movement of small motor for systems 1 and 2 and lighting of the bulb for system 3). Finally, they were asked to construct an energy representation for each system and to justify their answer. Figure 5 shows the representations the students were expected to make.

FIGURE 5



Schematic representations the children are anticipated to construct during the 5th unit of the teaching intervention (post - test)

It was expected that the students would apply the energy chain model to all of the phenomenological situations, irrespective of whether they had been presented during the teaching intervention or not. The 5th unit was used as an assessment unit (post – test).

Data collection and analysis
Methodologically this research belongs to the experimental research projects. The pre and post-test were the method of data collection. This paper focuses on the method and results related to the data concerning the conceptual component of the scientific knowledge. To be more specific, to the data related to the mental representations

constructed by the students for the energy concept after their participation in the previously mentioned teaching activities[3].

The purpose of the pre-test was to determine if the groups were able to represent the function of the physical systems 'battery – light bulb', 'battery – small motor' and 'battery - thermal resistor - hand' as object chains in terms of function or distribution. In other words, the pre-test assessed if and when the students spontaneously utilized their linear causal reasoning. The pre – test assignments were the following:

1. the students were asked to construct object chains with the cards given to them for the function of the three physical systems
2. the students were asked the following questions: «Why does the light bulb shine?», «Why does the motor turn?» and «Why does our hand get warmer?»

The purpose of the post-test was to determine if the groups[4] were able to construct energy chain representations for the function of the physical systems 'battery – small motor', 'light stand - photovoltaic cell – small motor' and 'light stand - photovoltaic cell – light bulb' with the assistance of the cards given. Picture 1 shows an energy chain \representation made by a group.

The groups were initially asked to connect and operate the physical systems. Afterwards the following assignments were given:

1. for the system 'battery – small motor' «Construct the energy chain for the phenomenon of the motor movement», for the system 'light stand – photovoltaic cell – small motor' «Construct the energy chain for the phenomenon of the motor movement» and for the system 'light stand - photovoltaic cell – light bulb' «Construct the energy chain for the phenomenon of the light bulb shining».

3 Similar to the students who were given the tests, the four teachers who observed the teaching intervention were given opinion questionnaires. The purpose of the questionnaire was that the teachers evaluate the content, the level of difficulty and the degree of interest for the teaching intervention for themselves and for the students. Despite the fact that the questionnaire results on the level of acceptance and evaluation of the teaching intervention are interesting, they are not part of this particular paper.

4 Various reasons led us to the methodological choice of collecting data not from individual students but from student pairs. The main reason was practical and was related to the difficulties and the constraints of conducting an in vivo research (mainly time constraints). This choice is also justified by the research tendencies (which align with the so called socio-cultural approach of teaching and learning) which suggest that the group itself can be considered as a study unit (Dillenbourg et al., 1996). In our case, the study was not process oriented (which requires different methodological analysis tools), and was confined to the cognitive product of the group, which was utilized as an indication of the cognitive progress of the students that participated in the teaching intervention.

PICTURE 1

A group of students constructs an energy chain representation

2. for the systems 'battery – small motor' and 'light stand – photovoltaic cell – small motor' «Explain why the motor turns» and for the system 'light stand - photovoltaic cell – light bulb' «Explain why the light bulb shines».

The first two physical systems were known to the students, since they had constructed their representations during the teaching intervention, while the third system was unknown.

The pre-test and post-test data for question (a) were collected by taking pictures of the energy chain representations made by the groups and for question (b) by recording and transcripting the children's answers.

RESULTS AND DISCUSSION

Pre-test

The pre – test results are presented on Tables 2, 3 and 4. These tables show the absolute and the relative frequencies of the groups which answered questions (a) and (b). The children's answers on question (a) were assigned to two categories: 'Yes' when the students correctly constructed the energy chains using the cards and 'No' when they didn't. The answers on question (b) were assigned to three categories: Category *C1* includes the students' answers where the activity of the three physical systems was explained as object chains in terms of function (i.e. the lighting of the bulb is due to the battery). Category *C2* includes the answers where the function of the three physical systems was explained as object chains in terms of distribution (i.e. the battery gives electricity to the light bulb so it shines). Finally, category *C3* includes the answers which lack a naturalistic explanation and include other types of explanations such as teleological (Christidou, 2005; Koliopoulos et al., 2009).

According to the pre –test data, a significant percent of the groups was able to construct schematic representations of the three physical systems' function (71,2% for the system 'battery – light bulb', 73% for the system 'battery – small motor' and 63,5% for the system 'battery – thermal resistor'). Irrespective of whether the groups were able to place the cards in the proper order, the majority of the groups justified the schematic representations using naturalistic causal reasoning. In other words, they described the three physical systems either as objects chains in terms of function (27% for the system 'battery – light bulb', 34,6% for the system 'battery – small motor' and 30,8% for the system 'battery – thermal resistor'), or as object chains in terms of distribution (59,5% for the system 'battery – light bulb', 55,8% for the system 'battery – small motor' and 53,9% for the system 'battery – thermal resistor'). Approximately 10% of the groups used non naturalistic reasoning.

Some characteristic answers by groups describing the physical systems as object chains in terms of function are the following: 'the battery is connected with the cable

Table 2

Pre-test: Absolute and relative frequencies of children's answers on questions (a) and (b) with respect to the system 'battery - light bulb'

	Question (a)		Question (b)			
Classes	YES	NO	C1	C2	C3	Group total
T1	8 (61,6 %)	5 (38,4 %)	3 (23,0 %)	8 (61,6 %)	2 (15,4 %)	13 (100,0 %)
T2	9 (69,2 %)	4 (30,8 %)	6 (46,2 %)	5 (38,4 %)	2 (15,4 %)	13 (100,0 %)
T3	11 (84,6 %)	2 (15,4 %)	1 (7,7 %)	9 (69,3 %)	3 (23,0 %)	13 (100,0 %)
T4	9 (69,2 %)	4 (30,8 %)	4 (30,8 %)	9 (69,2 %)	0 (0,0 %)	13 (100,0 %)
Group total	37 (71,2 %)	15 (28,8 %)	14 (27,0 %)	31 (59,5 %)	7 (13,5 %)	52 (100,0 %)

Table 3

Pre-test: Absolute and relative frequencies of children's answers on questions (a) and (b) with respect to the system 'battery - small motor'

	Question (a)		Question (b)			
Classes	YES	NO	C1	C2	C3	Group total
T1	8 (61,6 %)	5 (38,4 %)	1 (7,7 %)	9 (69,3 %)	3 (23,0 %)	13 (100,0 %)
T2	11 (84,6 %)	2 (15,4 %)	7 (53,9 %)	5 (38,4 %)	1 (7,7 %)	13 (100,0 %)
T3	10 (77,0 %)	3 (23,0 %)	4 (30,8 %)	8 (61,5 %)	1 (7,7 %)	13 (100,0 %)
T4	9 (69,2 %)	4 (30,8 %)	6 (46,1 %)	7 (53,9 %)	0 (0,0 %)	13 (100,0 %)
Group total	38 (73,0 %)	14 (27,0 %)	18 (34,6 %)	29 (55,8 %)	5 (9,6 %)	52 (100,0 %)

TABLE 4

Pre-test: Absolute and relative frequencies of children's answers on questions (a) and (b) with respect to the system 'battery - thermal resistor'

	Question (a)		Question (b)			
Classes	YES	NO	C1	C2	C3	Group total
T1	7 (53,9 %)	6 (46,1 %)	5 (38,4 %)	8 (61,6 %)	0 (0,0 %)	13 (100,0 %)
T2	11 (84,6 %)	2 (15,4 %)	8 (61,6 %)	3 (23,0 %)	2 (15,4 %)	13 (100,0 %)
T3	6 (46,1 %)	7 (53,9 %)	2 (15,4 %)	8 (61,6 %)	3 (23,0 %)	13 (100,0 %)
T4	9 (69,2 %)	4 (30,8 %)	4 (30,8 %)	9 (69,2 %)	0 (0,0 %)	13 (100,0 %)
Group total	33 (63,5 %)	19 (36,5 %)	19 (36,5 %)	28 (53,9 %)	5 (9,6 %)	52 (100,0 %)

and the light bulb shines' (T18), 'we place the cables in the battery and the small motor works' (T23) and 'the battery makes it [the thermal resistor] get warmer' (T37). The majority of the groups described the physical systems as object chains in terms of distribution. These groups introduced a 'transitive entity' in between the various objects. For example, 'the battery gives current to the cable and the light bulb shines' (T111), 'the battery has electric and with the cables we connect the battery to the small motor and the electric passes through the cables and the small motor turns' (T21) and 'the battery gives a thing to the thermal resistor and it gives heat' (T13). The children used various words to name this entity such as 'electric', 'electricity', 'current', 'power' 'heat'. Several groups used the word 'energy' ('because the battery has energy and it makes our hand warm because energy is warm' – T31). The groups that did not utilize naturalistic reasoning usually expressed a teleological reasoning ('the small motor turns to cool us down' – T410) or a tautological reasoning ('… because we made the chain [with the cards] – T34).

The above results confirm to a large extent the findings of previous studies, according to which several preschool children (5-6 years old) spontaneously compose 'pre -energy' mental representations for the function of physical systems where a battery is used as an energy source (Koliopoulos et al, 2009; Kontogiannatou, 2009). It seems that in our research many children not only spontaneously stated 'pre – energy' mental representations for the same or similar physical systems but also, with the help of this type of reasoning, gave meaning to symbolic representations which they were able to construct. Furthermore, first grade students seem to formulate the reasoning 'object chains in terms of distribution' easier and in a larger percent than preschool children. This could be attributed to either the fact that first grade children were asked to make the schematic representation of the energy chain which includes, potentially, the action of an object on another object and / or the fact that they had already shaped a cognitive structure which is referred to as 'transitive thought' (Piaget & Garcia, 1971, 1983; Ravanis, Papamichael & Koulaidis, 2002). This structure contains an intermediate causal factor which links (without always being identified with) the initial cause to the final result of the phenomenon. This is similar to the case when children refer to the factor ‘impulse’ or ‘momentum’ when they attempt to explain the transfer of movement from one ball to another (Piaget & Garcia, 1983). In our current study this factor assumes various names, including the term ‘energy’. The nature of this factor was not clearly defined in the majority of the children’s explanations. In the few occasions where the factor was defined, it assumed either the characteristics of a substance (‘electricity is warm’ – T110) (Duit, 1987), or the characteristics of a physical action (‘the battery has power, which passes through the cable and the small motor turns’ – T43). Further qualitative research is needed to clarify the nature and characteristics of this mental representation children of this age use.

Post – test

It should be noted that before the post – test questions were asked, all groups easily and successfully constructed the circuits of the three physical systems used for the post – test. The post – test results are presented on Tables 5, 6 and 7.

According to the post –test data of these tables, a significant percent of the groups was able to construct representations of the three physical systems’ function (92,3% for the system ‘battery – small motor’, 84,6% for the system ‘light stand – photovoltaic cell – small motor’ and 69,2% for the system ‘light stand – photovoltaic cell – light bulb’). A comparison between the pre – test and post – test answers regarding the physical situation common to both tests (‘movement of a small motor based on a battery’) reveals a clear shift of the group answers towards the construction of accurate schematic energy chain representations (from 73% to 92.3%). The percent of the groups that constructed correct schematic representations for the other two physical systems is also significant, especially for the third system (‘lighting of a bulb using a photovoltaic cell’) which hadn’t been presented previously in class.

In addition, the percent of the groups that utilized the reasoning ‘object chains in

Table 5

Post-test: Absolute and relative frequencies of children’s answers on questions (a) and (b) with respect to the system ’battery - small motor’

	Question (a)		Question (b)			
Classes	**YES**	**NO**	**C1**	**C2**	**C3**	**Group total**
T1	11 (84,6 %)	2 (15,4 %)	0 (0,0 %)	13 (100,0 %)	0 (0,0 %)	13 (100,0 %)
T2	13 (100,0 %)	0 (0,0 %)	0 (0,0 %)	13 (100,0 %)	0 (0,0 %)	13 (100,0 %)
T3	13 (100,0 %)	0 (0,0 %)	0 (0,0 %)	13 (100,0 %)	0 (0,0 %)	13 (100,0 %)
T4	11 (84,6 %)	2 (15,4 %)	0 (0,0 %)	13 (100,0 %)	0 (0,0 %)	13 (100,0 %)
Group total	48 (92,3 %)	4 (7,7 %)	0 (0,0 %)	52 (100,0 %)	0 (0,0 %)	52 (100,0 %)

TABLE 6

Post-test: Absolute and relative frequencies of children's answers on questions (a) and (b) with respect to the system 'battery - small motor'

	Question (a)		Question (b)			
Classes	YES	NO	C1	C2	C3	Group total
T1	10 (77,0 %)	3 (23,0 %)	1 (7,7 %)	12 (92,3 %)	0 (0,0 %)	13 (100,0 %)
T2	9 (69,2 %)	4 (30,8 %)	0 (0,0 %)	13 (100,0 %)	0 (0,0 %)	13 (100,0 %)
T3	9 (69,2 %)	4 (30,8 %)	1 (7,7 %)	12 (92,3 %)	0 (0,0 %)	13 (100,0 %)
T4	11 (84,6 %)	2 (15,4 %)	0 (0,0 %)	13 (100,0 %)	0 (0,0 %)	13 (100,0 %)
Group total	39 (75,0 %)	13 (25,0 %)	2 (3,8 %)	50 (96,2 %)	0 (0,0 %)	52 (100,0 %)

TABLE 7

Post-test: Absolute and relative frequencies of children's answers on questions (a) and (b) with respect to the system 'photovoltaic unit - light bulb'

	Question (a)		Question (b)			
Classes	YES	NO	C1	C2	C3	Group total
T1	10 (77,0 %)	3 (23,0 %)	0 (0,0 %)	13 (100,0 %)	0 (0,0 %)	13 (100,0 %)
T2	9 (69,2 %)	4 (30,8 %)	0 (0,0 %)	13 (100,0 %)	0 (0,0 %)	13 (100,0 %)
T3	8 (61,6 %)	5 (38,4 %)	1 (7,7 %)	12 (92,3 %)	0 (0,0 %)	13 (100,0 %)
T4	9 (69,2 %)	4 (30,8 %)	0 (0,0 %)	13 (100,0 %)	0 (0,0 %)	13 (100,0 %)
Group total	36 (69,2 %)	16 (30,8 %)	1 (2,0 %)	51 (98,0 %)	0 (0,0 %)	52 (100,0 %)

terms of distribution' increased significantly, while the reasoning 'object chains in terms of function' and the teleological or tautological type of reasoning almost disappeared. This change could be explained by the fact that during the post – test the children explained the function of the three physical systems by verbally describing the schematic representation they had previously made.

Despite this possible explanation, we are justified in assuming that many children have progressed to this type of reasoning precisely because they were able to construct without any assistance the correct energy chain schematic representation. In addition, we believe that the percent of the groups that made the correct schematic representation for the system 'light stand - photovoltaic cell – light bulb', which had not been taught during the teaching intervention, is particularly satisfactory (over 2/3 of the groups). Furthermore, certain student statements are not simple reproduction of the words on the cards, but a complete sentence associating the energy chain model with the corresponding phenomenology ('the light stand gives light to the photovoltaic cell, which gives electricity to the small motor, which turns' – T23). On the other hand, for those children that are classified in category C2 without having correctly constructed the schematic representation, we can't be certain if they have begun constructing an intermediate causal entity in between the various objects that compose the physical system. Further qualitative research is needed in order to determine if and to what extent children utilize this specific reasoning in different contexts after the particular teaching intervention.

Conclusions

This research was an attempt to verify the hypothesis according to which primary school children are able to construct a qualitative energy model after a relevant teaching intervention. The research results indicate that the suggested teaching activities contribute to the activation of a linear causal reasoning, a type of reasoning utilized by children from a very young age and in principle compatible with the construction of a qualitative explanatory model. Further research is needed in order to determine the reasons for this contribution. We believe that by using qualitative methods, such as class observation and individual interviews, the role of the following three parameters should be examined: (a) the selected physical systems, (b) the suggested schematic representation for the construction of the model and (c) the activities – problem sets discussed during the teaching intervention. In addition, we need to broaden the student sample, the phenomenological application field of the qualitative energy model and the teaching circumstances in order to determine the application limits of the particular research.

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