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Constructing the "Energy" Concept and Its Social Use by Students of Primary Education in Greece

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Introduction

During the last 30 years or so, in Greece and worldwide too, there has been significant development in research focused on the introduction of the energy concept at several educational levels, as a result of the concept's scientific importance and the social interest it induces (Domenech et al. 2007; Driver & Millar 1986; Millar 2005; Koliopoulos and Constantinou 2012; Chen et al. 2014; Bächtold 2017). In the late 1970s, the first relevant curricula made their appearance as educational systems in industrial countries reacted to the oil crisis and, more generally, to the energy crisis that had stricken them at the beginning of that decade. At the same time, research groups, spawned mostly from the abruptly expanding field of Science Education, were examining students' notions and mental representations of the energy concept. Thus, the link between the potential development of innovative teaching interventions aimed at the learners' cognitive growth and the proper modification of attitudes regarding the social use of energy (energy saving, etc.) emerged.

During this long time period, only few studies addressed the learning and teaching of the energy concept in *preschool and primary education*. However, these studies seem to give prominence to relatively young children's capacity to construct pre-energy mental representations,

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although the energy concept is considered a priori exceptionally abstract to teach at these educational levels (Koliopoulos and Argyropoulou 2011; Colonnese et al. 2012; Hammer et al. 2012; Koliopoulos 2014; Papadouris and Constantinou 2011). One question that has not been sufficiently answered yet is if capable, at what age are children first able to construct quantitative features of the energy concept and possibly proceed to mathematical descriptions of it? A second question that also remains partially unanswered is whether or not it is possible for students to connect any conceptual content of knowledge of the energy concept they might construct with everyday life issues related to energy, such as energy saving and measuring electrical energy consumption, and to describe complex technological systems using energy terms.

The present study addresses both of the above questions. More specifically, we present the results of research related to the design, application, and evaluation of a teaching intervention for the energy concept, aimed at 10–11-year-old Greek students. Firstly, we document and justify the nature, characteristics, and content of school knowledge that is portrayed by the proposed specific sequence of teaching units. Consequently, we present the results of empirical research, the goal of which was to examine if students who took part in the teaching intervention have shown any cognitive progress and especially if they have constructed qualitative and, primarily, quantitative features of the school energy-related knowledge as well as whether they have managed to correlate this knowledge with everyday life issues.

Theoretical Framework

A Framework for Analyzing and Designing Science Curricula and Teaching Activities

The concept of *didactic transposition* indicates the profound changes of scientific knowledge in order to obtain features of school knowledge. According to Chevallard (1985), didactic transposition is the net result of the modifications that the content of scientific knowledge has to undergo whenever the latter is meant to be the teaching objective. Martinand (1986) enriched the content of didactic transposition by introducing the concept of *social reference practice*, claiming that knowledge that is about to be a teaching objective cannot merely be the transposition of knowledge deriving from scientific research, but of knowledge stemming from other practices and social activities, for instance, technological and productive or even domestic and cultural activities.

From the angle of didactic transposition, content analysis of a series of Greek and international thematic science curricula has led to the formation of a classification for the latter (Koliopoulos & Ravanis, 1998; Koliopoulos & Ravanis 2000a; Koliopoulos & Constantinou 2005; Koliopoulos et al. 2005; Koliopoulos et al. 2012). According to this classification, these curricula can be categorized into three broad classes, each one constituting a framework for the relevant type of transposition of scientific knowledge to its school version. The general characteristics of this classification can *justify* the elements of structure, content, and activities that the actual curricula recommend.

The proposed classification is based on the distinction between three frameworks served by the school science curricula. Each of these frameworks refers to the way a school science curriculum manipulates concepts, methodology, or cultural characteristics of one or more thematic or conceptual units. They are referred to as the *traditional framework*, the *innovative framework*, and the *constructivist framework* of the science curriculum.

The Traditional Framework This framework is characterized by the following four elements that emerge as the didactic transposition of the three dimensions of scientific knowledge (conceptual, methodological, cultural) into school knowledge:

(a) The juxtaposition, dispersion, and/or fusion of various conceptual frameworks due to disintegration of thematic or conceptual units (conceptual dimension),
(b) The mathematical, in higher grades of education, or the "pseudo-qualitative," in lower grades, handling of science concepts (conceptual dimension),
(c) The empirical–experimental approach, which is rooted in the perception that scientific knowledge is produced by empirical data, usually in the form of one reference experiment that is sufficient in order to introduce, confirm, and apply a relation among concepts (methodological dimension), and
(d) The limited use of the cultural features of scientific knowledge (cultural dimension), which is usually expressed by the apposition of technological applications of scientific knowledge.

As detailed below, the abovementioned four features are declared null and void in the context of the other two frameworks, which constitute the epistemological background of the research design of this study.

The Innovative Framework This framework is characterized by the following four elements that emerge as the didactic transposition of the three dimensions of scientific knowledge (conceptual, methodological, cultural) into school knowledge:

(a) The formation of *broad* thematic/conceptual units in which the emphasis is placed on the structure of the unit and/or the so-called directed theme (conceptual dimension).
(b) The *in-depth* discussion of a conceptual framework which is characterized by a *qualitative/semi-quantitative* approach of science concepts that strives o establish a dialectic relationship between the meaning and the symbolic representations of a conceptual network (conceptual dimension).
(c) The effect of the *hypothetico-deductive* methodological approach (methodological dimension). Within the innovative framework, the hypothetico-deductive approach emerges from within the design of "teaching activities-problems," in which the hypothetical substance of scientific knowledge is shown. In such a context, scientific knowledge does not directly arise out of experience and observation, but arises from the study of an open problem. The abovementioned approach is compatible with the so-called inquiry-based teaching and learning. At the same time, the role of experimental teaching is upgraded, since it is considered as the natural context for the solution of the recommended problems (Hodson 1990).
(d) The meaningful (and not superficial) relationship between the conceptual and the methodological components of scientific knowledge with the history, society, and/or technology (cultural dimension). From the perspective of the innovative framework everyday life issues, numerous technological matters or historical scientific documents themselves suggest *starting points* and negotiable settings for the conceptual and the methodological components of scientific knowledge. Therefore, certain cultural features are proclaimed essential elements of the curriculum design and the educational procedure.

The Constructivist Framework For the present study, we perceive the constructivist framework for the science curriculum as an alternative tool for the analysis and design and not as an instructional method which has been severely criticized (Millar 1989; Solomon 1994). According to the approach taken, students' mental alternative representations in combination with didactic strategies for their modification provide information that may lead to an in-principle formulation of teaching aims and goals based on specific learning hypotheses and afterwards to the design of teaching material in a smaller or larger scale (Koliopoulos 2006).

The constructivist framework seems to be completely compatible with the innovative one. The introduction of broad thematic/conceptual units to instruction and, even more, the *in-depth* dealing with a conceptual framework fosters the insertion and discussion of the students' mental representations of elements within the curriculum. Also, the use of the hypothetico-deductive approach is appropriately fitted with didactic strategies used for the modification of students' mental representations, as in every occasion these strategies require a (authentic) procedure for validating hypothetical explanations of reality.

The frameworks we presented in this section are based on ideas that are in principle compatible with other international frameworks for the analysis and the design of science curricula and teaching activities (Meheut & Psillos 2004; Ruthven et al. 2009; Tiberghien 2000). These ideas guide the basic principles that govern the design of the proposed teaching sequence ("Energy School Knowledge in the Context of 'Innovative-Constructivist' Frameworks: the Model of Energy Chains") and they are reflected in the teaching goals and the content of the teaching sequence ("The Energy Teaching Sequence: Objectives and Content"). Additionally, these ideas are in line with the design principles that govern the questionnaire that evaluates the students' potential conceptual development ("The Dependent Variable: the Students' Performance and the Evaluation Questionnaire" and "Data Analysis").

Energy School Knowledge in the Context of "Innovative-Constructivist" Frameworks: the Model of Energy Chains

In contrast to the traditional framework that deals with every science concept in the same manner, the energy concept is preferentially treated within the innovative framework; for a substantial part of the framework, the concept is integrated as a *broad conceptual unit* or as an *organizational principle*. In this context, energy is introduced as a fundamental concept in the form of the *energy chain model*. The conceptual model of energy chains, as it has been implemented from time to time in instruction (Agabra et al. 1979; Falk & Hermann 1981; Haber-Schaim 1983; Koliopoulos & Tiberghien 1986; CLISP 1987; Koliopoulos & Ravanis 2000b; Koliopoulos et al. 2012; Papadouris and Constantinou 2011), does not preserve a uniform manifestation; however, it demonstrates several basic features that could be recapitulated as follows:

(a) It is based on a structure that includes storage, transfer, transformation, measurement, conservation, and degradation as fundamental distinctive qualities of energy. It essentially constitutes a form of the didactic transposition of science knowledge into its school version that is mainly connected to (i) the rich tradition of energy syntheses and the emergence of the conservation of energy principle deriving from the nineteenth century (Kuhn 1977) and (ii) the conceptual framework of macroscopic thermodynamics as it is formed in the context of modern science either as axiomatic (Zemansky & Dittman 1987) or for engineers (Baehr 1978). Explicitly, for this particular field, the energy chain model seems to be by far the most epistemologically valid transposition of scientific knowledge into school knowledge.

(b) It can take various qualitative and/or quantitative representational forms, such as the pre-energy representations of *chain of objects based on their function* (abbreviated as *function* mental representation) and *chain of objects based on energy distribution* (abbreviated as *distribution* mental representation) (Lemeignan & Weil-Barais 1994), energy flow charts (Falk et al. 1983; Viglietta 1990), or energy chains that emphasize the differentiation among the storage and the transfer of diverse energy forms (Tiberghien & Megalakaki 1995).

(c) The internal structure of the conceptual model of energy chains is compatible with the so-called *linear causal reasoning*. According to Halbwachs (1971), this causal explanation constitutes the preferential way for representing natural reality both for adults and children. When students begin to use this type of reasoning, regardless of the educational level they belong to (starting from preschool up to upper secondary school), it has been widely noticed that they are capable of constructing qualitative and, to a degree, quantitative expressions of the energy chain model (Lemeignan & Weil-Barais 1994; Tiberghien 1996; Koliopoulos and Ravanis 2001; Koliopoulos and Argyropoulou 2011; Koliopoulos 2014). Finally, it has been suggested that the reliable use of this model is limited, since it may lead to erroneous explanations, especially on those cases that the explanation of the phenomena demands mathematical models (Meli et al. 2016; Rozier & Viennot 1991).

The Energy Teaching Sequence: Objectives and Content

The key objective of the proposed teaching sequence is for students to evolve their mental representations of the energy concept and strive for representations that are more compatible with the relevant scientific models. Explicitly, the main objective is the construction of basic features of the qualitative and, more importantly, of the quantitative dimensions of the energy chain model (conceptual objective). More specifically, students should be able to (a) take advantage of the qualities of storage, transfer, and transformation of energy in order to explain phenomena such as lighting a lamp, the motion of a motor, and the heating of a resistor, (b) measure electric energy amounts and explain the relevant phenomena with the help of the quantitative elements (amount of energy, energy supply/electric power) of the energy chain model, and (c) transfer this knowledge in order to successfully explain respective phenomena in the domestic environment (function of the energy meter, energy saving). The basic principles of the innovative-constructivist frameworks ("A Framework for Analyzing and Designing Science Curricula and Teaching Activities") govern the choice of the phenomenological field for the application of the energy concept as well as its conceptual content. The phenomenological field includes carefully selected natural situations. These situations, on the one hand, are compatible with a qualitative/semi-quantitative approach of the science concepts and especially the one of energy (Koliopoulos & Tiberghien 1986). On the other hand, they challenge the students to express their spontaneous mental representations (pre-energy representations) that can be later integrated in the appropriate teaching material in order to evolve to scientific knowledge, compatible with the energy chain model (Koliopoulos & Ravanis 2001).

Another goal is to develop appropriate teaching activities-problems that will lead the students to hypothesis formulation, need for experimentation, and, ultimately, the necessity of finding an energy explanatory framework (methodological objective).

Finally, an important objective of the proposed teaching sequence is to correlate some social uses of energy with the conceptual content and the respective phenomenological field. This could be achieved if the discussion of the concept was integrated into the study of relevant issues or natural phenomena that occur in everyday life and are approachable by children in the specific age group (cultural objective). In this case, an effort has been made to connect the quantitative dimension of the energy chain model to the domestic energy meter and the measurement of the amounts of energy that are transferred in the house.

The suggested teaching sequence consists of four thematic units. Table 1 presents the structure of the units and the subsections in the form of respective titles (the titles are the same with the titles of the respective worksheets that have been given to the students during the intervention) and, for each subsection, the main teaching activity-problem that the students have to deal with, the related phenomenological field, and the corresponding explanatory framework, as well as a brief description of the anticipated evolvement of the students' mental representations at the conceptual field. As shown in Table 1, the formation of the teaching units derives from the fundamental principles of the innovative-constructivist frameworks, according to which the appropriate activities-problems are introduced in the instruction. These activities-problems are based on the specific learning hypotheses that they will facilitate to the students to make the expected progress on their mental representations.

Each one of the above teaching units is divided into three subsections and the intervention of every subsection corresponds to a 90-min teaching period. The images that are presented herein account for different subsections and have been captured during the intervention. In Image 1, one can see arrangements of the intervention's phenomenological field (subsection 1). Image 2 presents the Joulemeter device, which helped the students measure amounts of energy (subsection 7). Finally, in Image 3, a group of students and their instructor are shown while they measure amounts of energy using the school's energy meter.

The students have to fill out a worksheet for each subsection. The worksheets were designed in a manner that simulates the worksheets of the existing textbook. To this effect, another element of the educational environment is preserved; the fact that the students perceive this as a familiar feature reduces the chances of affecting the final result with factors that are external to the suggested knowledge. Additionally, the worksheets were designed to be interesting, pleasant, comprehensible, and brief enough in order to be completed by as many students as possible.

The linguistic code that was used in the titles as well as in the rest of the document is of moderate formality (Koulaidis et al. 2002), in order to achieve sufficient readability. The worksheets include (a) designs of technological arrangements stemming from the school laboratory that the students have to assemble and operate themselves, (b) questions they have to answer for explaining the observed phenomena, (c) activities for the construction of symbolic representations of the energy chain model for the various arrangements to work, (d) problems that help the students approach and understand the concept in discussion more thoroughly, and (e) brief passages containing information about technological topics or issues of everyday life.

Table 1 Teaching intervention units

	S/n	Title	Activity-problem	Natural phenomena	Conceptual framework	Expected progress of students' mental representations
Introduction to the energy chain model	1	"I make simple electric devices"	Why does the lamp turn on? Why does the fan turn around?	-Lamp switching on using a battery -Motion of a body using a battery		-Emerging students' pre-energy reasoning (activating "function" and/or "distribution" mental representations)
	2	"I explain by using symbols"	How do we give an explanation using symbols (I)?	-Lamp switching on using a battery -Motion of a propeller using a battery -Weight lifting using a battery	Introduction of a qualitative form of the energy chain model	-Relating "distribution" mental representation with qualitative features of the energy chain model
	3	"I draw more energy chains"	How do we give an explanation using symbols (II)?	-Lamp switching on using a dynamo -Resistor heating using a battery	Extension of the phenomenological field/application of a qualitative form of the energy chain model	-Applying of an "enriched distribution" mental representation -Differentiating the concepts "I have energy" and "I give energy"
Energy as quantity	4	"We provoke more intense phenomena"	Why does the lamp light brighter; Why does the fan turn around faster?	-Lamp switching on using two batteries (connected in series) -Motion of a body using two batteries (connected in series)		-Emerging students' "quantitative" pre-energy reasoning (activating a "quantitative distribution" mental representation)
	5	"I make changes in the energy chains"	How do we give an explanation using symbols (III)?	-Lamp switching on using two batteries -Motion of a body using two batteries	-Introduction of a quantitative form of the energy chain model	-Giving quantitative features to the "enriched distribution" mental representation
	6	"There are lots of battery types…"	What should we do to keep a lamp turned on in the same way but for longer time?	-Lamp switching on using two batteries (connected in parallel) or a large capacity battery	-Differentiation of the energy quantity and energy supply concepts at a practical and symbolic level	-Giving quantitative features to the "enriched distribution" mental representation
Measuring energy	7	"I measure energy with a Joule meter"	How do I measure transferred energy?	-Lamp switching on using a battery -Motion of a body using a battery	-Introduction of a quantitative form of the energy chain model using Joulemeter measurements	-Relating the "quantitative distribution" mental representation with Joulemeter measurements

Table 1 (continued)

	S/n	Title	Activity-problem	Natural phenomena	Conceptual framework	Expected progress of students' mental representations
				-Resistor heating using a battery -Joulemeter readings		
	8	"Energy quantity and energy supply are different things"	Differences between energy and energy supply	-Lamp switching on using a battery -Motion of a body using a battery -Resistor heating using a battery -Joulemeter readings	Application of a quantitative form of the energy chain model (differentiating "energy quantity" and "energy supply" concepts)	-Relating the "quantitative distribution" mental representation with Joulemeter measurements
	9	"Energy saving is essential, but how?"	How do I save energy?	-Lamp switching on using a battery -Motion of a body using a battery -Resistor heating using a battery -Joulemeter readings	-Application of a "complete" quantitative form of the energy chain model	-Relating the "quantitative distribution" mental representation with the "saving energy" concept
Energy in everyday life	10	"Energy has its own price"	What do we pay to the Electric Company?	-Functional house model with lamps, motors, and heating resistors	-Application of a "complete" quantitative form of the energy chain model	-Relating the "quantitative distribution" mental representation with the "saving energy" concept
	11	"Electricity meters"	What and how does the electric meter	-School electrical installation and energy meter	-Application of a "complete" quantitative form of the energy chain model	-Relating the "quantitative distribution" mental representation with school energy meter and the "saving energy" concept
	12	"We are all responsible of saving energy"	Giving a meaning to the quantitative data relative to energy saving	-Quantitative data concerning energy crisis and energy saving	-Application of a "complete" quantitative form of the energy chain model	-Relating the "quantitative distribution" mental representation with quantitative data and the "saving energy" concept

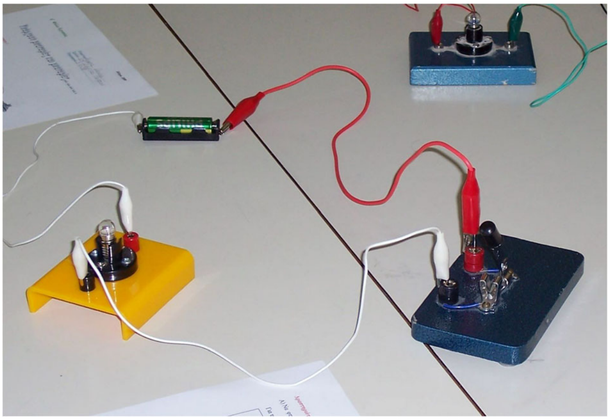


Image 1 Technological arrangements at the school lab from the phenomenological field of the teaching intervention

Methodological Framework

Design and Strategy of the Research

The strategy of the research is *pre-experimental* (Cohen et al. 2011). The essential feature of pre-experimental research is that researchers intentionally control and manipulate any conditions that define the instances they are interested in. In this sense, our work belongs to the so-called feasibility studies (Astolfi 1993) which mainly focus on examining the *potential* for cognitive progress within an in vitro research environment and not so much on the students' cognitive progress in real (in vivo) teaching conditions. In our research plan of double measurement on an experimental group, the various kinds of external variables (the way the students work in the classroom, the instructional method, the teacher's personality and experience,

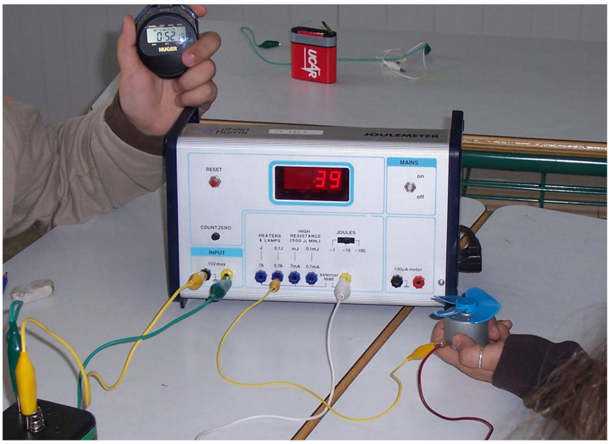


Image 2 The Joulemeter device the students used to measure amounts of energy

Image 3 A group of students and their teacher taking measurements of energy amounts using the school's energy meter

etc.) are beyond our control. We attempted to limit the effect of such factors by making appropriate choices for the sample, the instructor, and the teaching method in order to attribute the expected changes of the students' conceptual performance to the effect of the proposed school knowledge. The measurement of the dependent variable before and after the teaching intervention has been conducted with the *questionnaire* technique.

The Sample

The sample consisted of 39 students (20 girls and 19 boys) who came from two classes of different schools (10–11 years old/fifth grade). Both schools belong to the same demographic environment (same urban district with similar demographic factors, such as gender and ethnicity). The teaching intervention was applied by one of the two researchers in order to minimize the "instructor" effect. All students were informed of the reason and the purpose of the research process.

The Independent Variable: the Teaching Sequence and the Research Protocols

The structure and the content of the teaching intervention (par. 2.3) were converted to a series of *research protocols*. Research protocols combine two frameworks: the framework of action (instructional framework) and the framework of theory (science education framework). The framework of action prescribes the instructors' activities within the classroom during teaching and describes the anticipated activities from the students' side. The research interest in these particular protocols is focused on the correspondence between the actions that the students are called to implement and the expected cognitive progress (Tiberghien 1997). In this manner, the independent variable does not occur as a *black box*, as happens more often than not in various studies of this kind, but as a hypothesis formulation framework for the interpretation of the estimated change in the students' conceptual performance. Table 2 presents an example of a research protocol that has been used in our study.

The Dependent Variable: the Students' Performance and the Evaluation Questionnaire

The measurements of the dependent variable have been conducted with the pre-post questionnaire method (see Appendix), which included questions regarding the *conceptual dimension* of school knowledge. Extracted data concerning the remaining two dimensions of school knowledge will not be presented in the present study. The pre-test questionnaire was distributed to the students of both classes 2 weeks before the teaching intervention, whereas the post-test questionnaire, 2 weeks after the teaching intervention.

The aim of the pre-test was to reveal and record the students' alternative energy mental representations and more specifically their probable pre-energy reasoning. The aim of the post-test was to determine (a) if there was any *change* in the students' initial mental representations towards the construction of qualitative and quantitative features of the energy chain model and (b) whether or not there was an overall increase in the

Table 2 Example of a research protocol (Research Protocol 9)

Instruction (teaching action)		Science education (theoretical framework)		
Teacher's actions	Students' expected actions	Phenomenological field	School knowledge: conceptual framework for construction	Expected progress of students' mental representations
1. Ask students to fill in worksheet 9 (*WS9*), in which they have to construct pairs of symbolic representations of model *M3* in a part of the particular phenomenological field (*Q18*) 2. Provoke discussions about the students' tasks 3. Raise the issue of energy saving and ask students to provide energy saving solutions for the specific situations of *F1J*, *F2J*, *F3J* (*Q19*) 4. Provoke discussions about students' tasks	1. Fill in worksheet (*WS9*) by responding to questions *Q18* and *Q19* 2. Participate in the conversation about the factors that contribute to energy saving	*F1J*, *F2J*, *F3J*	Application of the quantitative energy chain model *M3*	-Relating the "quantitative distribution" mental representation with the "saving energy" concept

All research protocols include abbreviations that refer to special elements of the teaching sequences. In this particular research protocol, the abbreviation "F" corresponds to the natural situations that appear during the activities of the unit (*F1J* lamp switching on using a battery, *F2J* motion of a body using a battery, *F3J* resistor heating using a battery. "J" denotes the use of the Joulemeter). The abbreviations "Mx" corresponds to the type of the energy chain model that the students are provoked to use in order to explain the "F" natural situations (*M3* energy chain model with quantitative elements) number of satisfactory responses and, hence, any conceptual progress which could be perceived as *structured*.

Both the pre-test and post-test questionnaires included the same eight questions, which were divided into four groups of two. These sections of questions match the conceptual demands of the four units that constitute the teaching sequence. Each question included a closed query and an open one; the students were asked to justify their answer to the closed-type question. One additional question (question 9) was included in the post-test questionnaire in order to check the students' ability to construct a schematic energy representation of a domestic electrical system.

Data Analysis

This study presents the results in two levels of data analysis. The first level portrays comparative results of the students' answers in the pre-test and post-test questionnaires giving prominence to the students' mental representations before and after the teaching intervention. These results are derived from the quantitative results' analysis (tables of absolute frequencies of the categories that have been formed from the students' answers and justifications), as well as from the qualitative analysis (instances of *justifications* provided by the students).

Regarding the classification of the open questions, six categories have been formed depending on the adequate or inadequate use of the energy chain model's elements. In Table 3, one can see the different categories that the students' justifications belong to.

The second level of data analysis presents qualitative results that originated from the primary *categorical* variables of the first-level analysis after their conversion to secondary *hierarchical* variables. These variables indicate a satisfactory performance by students, or the lack of it. Subsequently, four categories were formed, as presented in Table 4.

This categorization could be useful for extracting conclusions regarding the students' development of their mental representations' progress, stagnation, or retrogression. More specifically, we performed a Wilcoxon test in order to examine the significance of the average shifted number of the students' justifications that are in line with the energy chain model. The Wilcoxon signed-rank test is based on the score differences between the two comparing conditions (pre and post) (Field 2009).

Research Results

The Construction of Qualitative Features of the Energy Concept (Questions 1, 2, and 9)

Figures 1 and 2 depict the absolute frequencies of the justifications provided by students, for questions 1 and 2, respectively.

There is a rather impressive shift of the justifications provided by students from mostly categories F, P, and D before the teaching intervention to categories A1 and A2 after the teaching intervention. In other words, the majority of students has steered away from the phenomenological/tautological justifications or the mental representation of *function* and has embraced causal justifications that constitute a more advanced qualitative form of the mental

Table 3 Categorization of the students' justification at the open-ended questions

Justification category	Justification characterization	Examples
A1	Correct and complete presentation of the conceptual features of the energy chain model (correct/complete energy representation)	"Joule is a unit of energy measurement. One can use Joule to measure the amount of energy that is transferred from the battery to the lamp and the heater. The transferred energy is not equal for both devices. The heater is more energy-consuming" (B4 post)
A2	Correct but incomplete presentation of the conceptual features of the energy chain model (incomplete energy representation)	"Joule measures the amount of energy for the water heating and the water heating has larger energy amount" (B7 post)
B	Incorrect presentation of the conceptual features of the energy chain model or presentation of a different conceptual framework (incorrect energy representation)	"That it [the lamp] has 10w in it and it can light up to that many Watt … it is also ascribed in order to put it in proper places, not to put a small lamp at an entire dining room" (B16 post)
F	Phrasing that includes phenomenological elements of the problem without referring to any conceptual framework and/or tautological justifications (phenomenological/-tautological representation)	"The lamp and the fan turn on because the two cables are connected to the two battery poles and to the two contacts of the lamp or the fan, resulting to the lighting of the lamp and the rotation of the fan's blades" (P17 pre) "If I connected two batteries, the lamp would light more brightly. The same thing happens with the heater; the water would be warmer" (B19 post)
P	Phrasing that includes exclusively pre-energy conceptual elements (pre-energy representation)	"The lamp receives less Joules, while the heater receives more" (P12 post)
D	No justification or statement of ignorance (no justification/ignorance)	

representation of *distribution*. More explicitly, during the post-test, several students formulated complete and concrete answers using the word "energy" as the intermediate action factor between an energy reservoir (i.e., a battery) and another reservoir or an energy converter (i.e., a small fan or lamp).

An indicative example of these shifts is one student's views (B.16) regarding question 1. On the pre-test, his answer was "The lamp lights because we connected it to the same battery. The blue wire to the minus sign and the red to the plus sign. The same thing happens in the second image"; on the post-test, conversely, his reply was "The reservoir namely the battery has energy and when we connect it to the motor or the lamp the propeller rotates and the lamp lights. Therefore the battery has energy and it offers it to the motor and the lamp and this is how the receivers work." Also, another student (B.17) has shifted towards the justification category A1 in his response to question 2, as his answer on the pre-test was "The water goes

Table 4 Categories of the justifications' evaluation norm

Category	Justification characterization
1	Adequate justification (category A1)
2	Intermediate justification (category A2)
3	Inadequate justification (categories B, F, P)
4	No justification (category D)

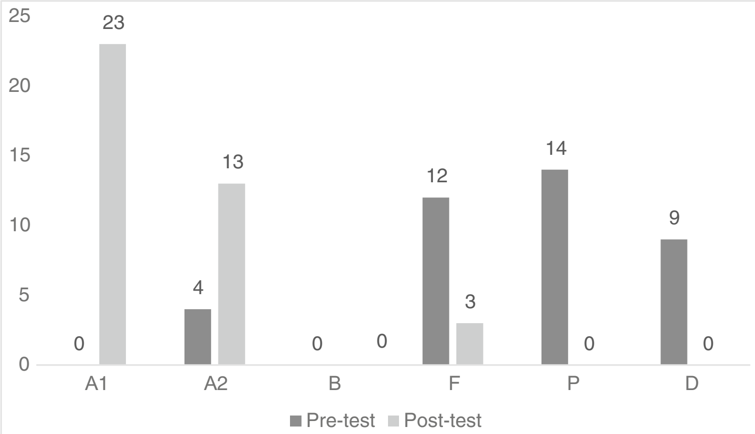


Fig. 1 Frequencies of the students' justification categories at question 1 (A1, correct/complete energy representation; A2, correct/incomplete energy representation; B, incorrect energy representation; F, phenomenological/tautological representation; P, pre-energy representation; D, no justification/ignorance)

first because what would the heater warm up? […] and then the battery because how would the heater work?", while on the post-test, he claims that "We firstly put the battery because it's an energy reservoir namely it gives energy to the heater, then we put the heater which is a converter and makes heat and then we put the water to be warmed up by the heater.". The abovementioned results are supplementary reinforced by the results derived from the analysis of the answers to question 9 that was added to the post-test.

This analysis reveals that the vast majority of students' constructions of the requested schematic representation are formed in either a correct and complete way (54% of the answers) or in a correct but incomplete way (43% of the answers). In Fig. 3, one can see a typical example of a correct and complete construction of the energy chain schematic representation, as regards question 9.

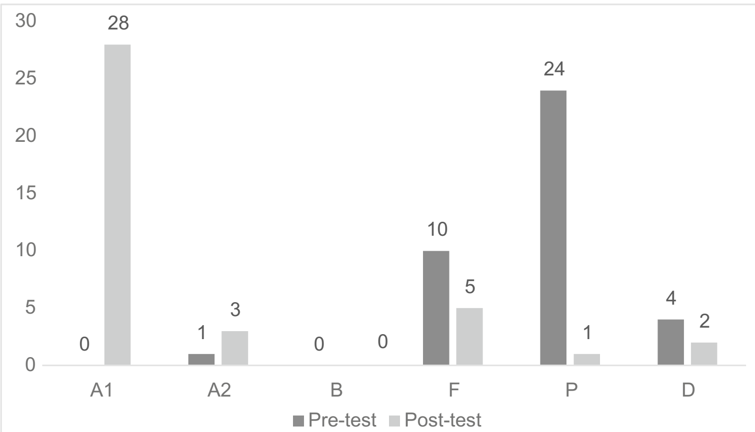


Fig. 2 Frequencies of the students' justification categories at question 2 (A1, correct/complete energy representation; A2, correct/incomplete energy representation; B, incorrect energy representation; F, phenomenological/tautological representation; P, pre-energy representation; D, no justification/ignorance)

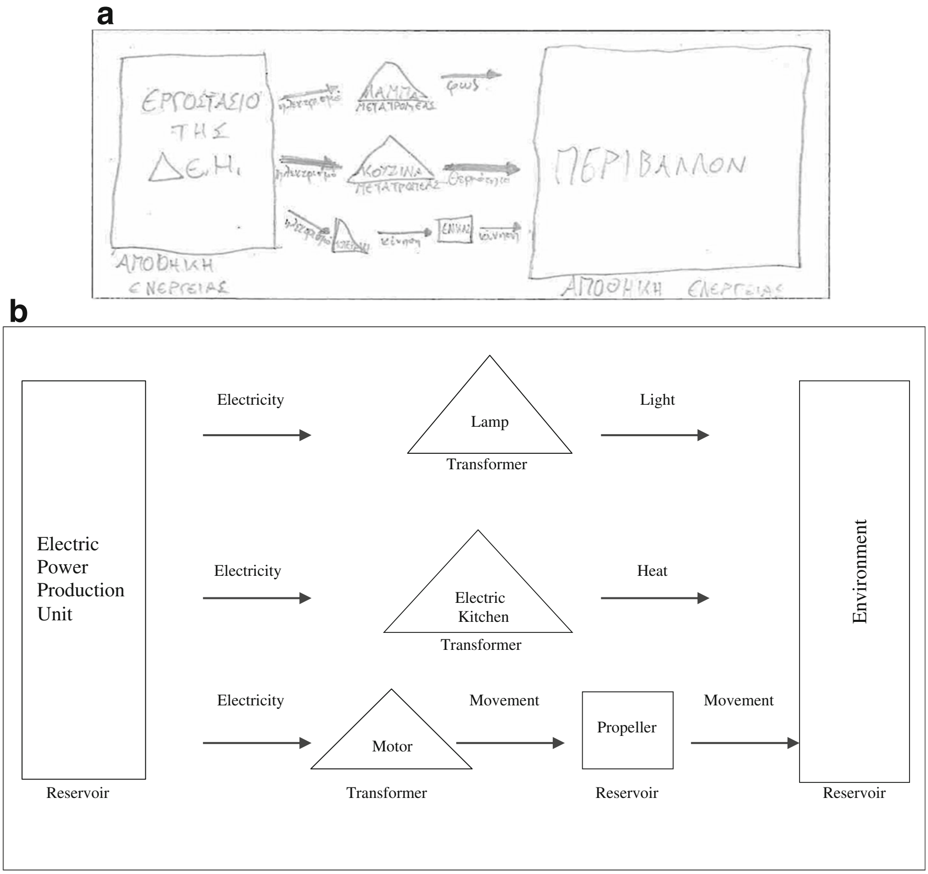


Fig. 3 **a** Correct and complete schematic representation of the energy chain model. **b** Correct and complete schematic representation of the energy chain model (translated from Greek)

The Construction of Quantitative Features of the Energy Concept (Questions 3 to 6)

Figures 4 and 5 illustrate the absolute frequencies of the students' justifications for questions 3 and 4, respectively.

In regard to question 3, we observe a remarkable shift of the justifications provided by students from categories F and P prior to the teaching intervention towards categories A1 and A2 following the teaching intervention. However, there still exists the relatively small number of students that persists in using qualitative pre-energy views during the post-test. Concerning question 4, the results are even less satisfying. For these two questions combined, the analysis of the students' justifications reveals that several of them appear to come closer to the notion that energy is a quantitative entity, but this convergence depends on the question's phenomenological background (e.g., possible lack of information regarding the operation of a bicycle's lamp using a dynamo may have influenced the students' answers). Nevertheless, the students' shift towards a more progressive version of the mental representation of "distribution,"

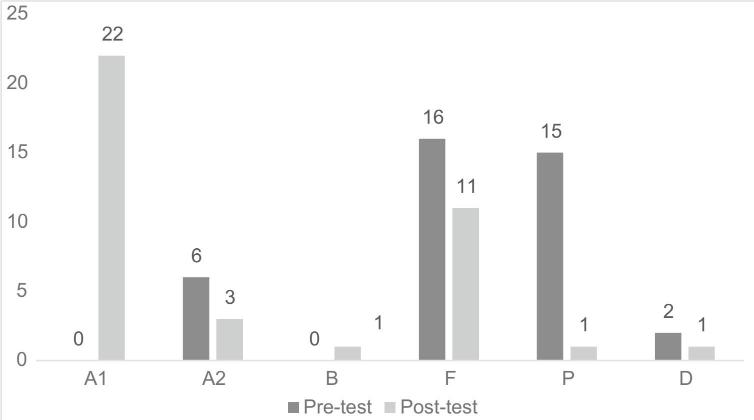


Fig. 4 Frequencies of the students' justification categories in question 3 (A1, correct/complete energy representation; A2, correct/incomplete energy representation; B, incorrect energy representation; F, phenomenological/tautological representation; P, pre-energy representation; D, no justification/ignorance)

which highlights the quantitative dimension of the energy concept (categories A1 and A2), is supplemented with an increase in the number of qualitative pre-energy mental representations (category P). An indicative example of this shift towards the quantitative dimension of energy is the viewpoint expressed in (P.12), question 3. His answer on the pre-test was "The lamp, if it was connected to two batteries, would light more brightly because we have two batteries. For the heater then because we also have two batteries it will be warmer"; however, on the post-test, he suggests that "The lamp will light more brightly and the heater will heat up the water even more in two minutes because the two batteries provide more energy in two minutes." A respective example for question 4 is the following: During the pre-test, a student (P.1) claimed that "She is forced to pedal harder because the dynamo touches the

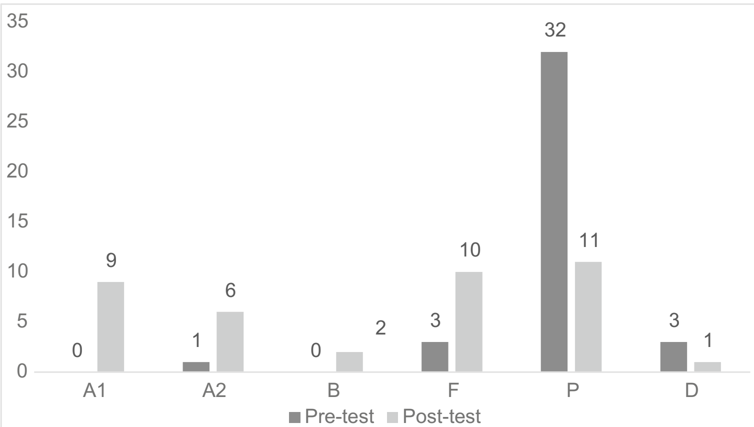


Fig. 5 Frequencies of the students' justification categories in question 4 (A1, correct/complete energy representation; A2, correct/incomplete energy representation; B, incorrect energy representation; F, phenomenological/tautological representation; P, pre-energy representation; D, no justification/ignorance)

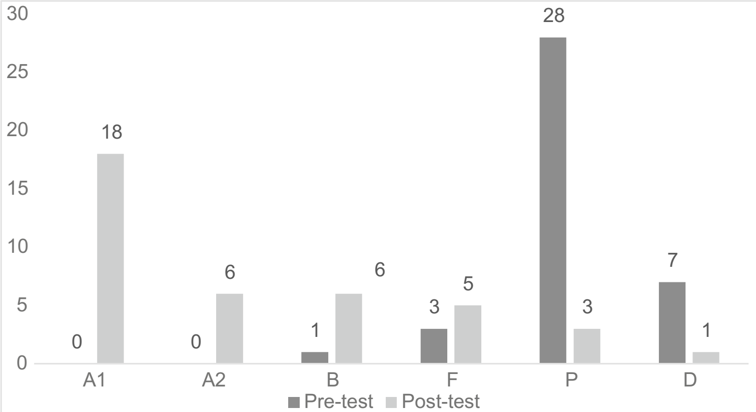


Fig. 6 Frequencies of the students' justification categories at question 5 (A1, correct/complete energy representation; A2, correct/incomplete energy representation; B, incorrect energy representation; F, phenomenological/tautological representation; P, pre-energy representation; D, no justification/ignorance)

wheel of the bicycle and if she slows down it would fall," while on the post-test, the same student claimed that "Because in order for the lamp to light it needs energy and this energy is produced by the movement, so the girl has to pedal harder in order to provide more energy."

Evidence that several students shifted towards the quantitative dimension of the energy concept, within the context of the energy chain model, is derived from our analysis of justifications to questions 5 and 6. Figures 6 and 7 show the absolute frequencies of the students' justifications for questions 5 and 6 correspondingly.

Comparing the justification categories in questions 5 and 6, we observe that several students moved from the categories F and P to the categories A1 and A2. Yet, there is a substantial difference. The students largely express pre-energy mental

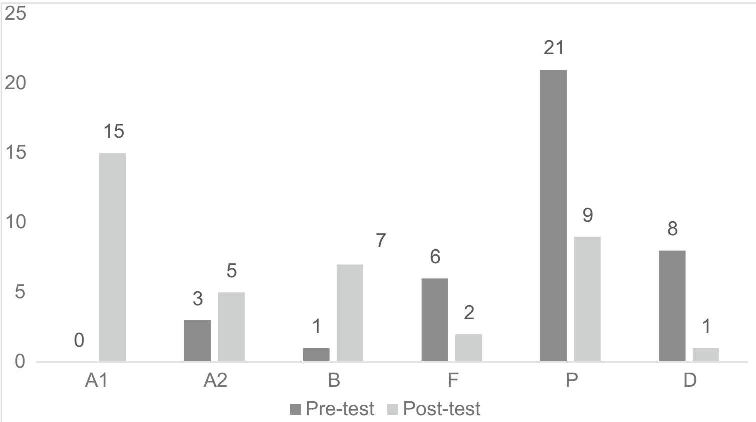


Fig. 7 Frequencies of the students' justification categories at question 6 (A1, correct/complete energy representation; A2, correct/incomplete energy representation; B, incorrect energy representation; F, phenomenological/tautological representation; P, pre-energy representation; D, no justification/ignorance)

representations during the question on the pre-test that concerns amounts of energy (with joule as the unit of measurement) and the percentage of those students that have shifted towards the categories A1 and A2 is rather high (above 75% for both categories). However, responses to the question involving energy supply/power show that the primary mental representation is mainly the one corresponding to the F justifications' category, while the shift towards the categories A1 and A2 is substantially less significant. In order to interpret these results, we claim that the students of this age, on the one hand, have the ability to perceive the quantitative dimension of the concept (as seen in the results from questions 3 and 4), but, on the other hand, are still unable to differentiate the concepts "amount of energy" and "energy supply/power" after the particular teaching intervention. Namely, they tend to construct an undifferentiated energy concept transfer that demonstrates some quantitative features. This assumption is further confirmed by the justifications' analysis for questions 7 and 8.

Typical examples of students' justifications are presented as follows. In question 5, a student (B.18) shifts from the view "It probably means that the force of the lamp is 10W" (pre-test) to the view "It means that the lamp has little power. It is a unit of measurement for the lamp's power" (post-test). However, in question 6, this specific student steered away from the point he initially expressed, which was "It means that the electric current that we spent to heat up the water is more than the lamp's" (pre-test) to the view "It means that the amount of energy transferred to the lamp is little, while from the reservoir a great amount of energy is transferred to the heater, because it is energy-consuming" (post-test).

The Construction of the Social Elements of the Energy Concept (Questions 7 and 8)

Figures 8 and 9 illustrate the absolute frequencies of the students' justifications for questions 7 and 8, respectively.

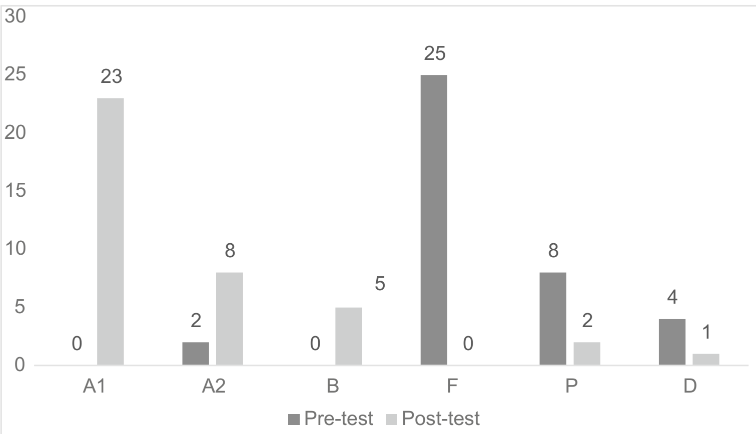


Fig. 8 Frequencies of the students' justification categories in question 7 (A1, correct/complete energy representation; A2, correct/incomplete energy representation; B, incorrect energy representation; F, phenomenological/tautological representation; P, pre-energy representation; D, no justification/ignorance)

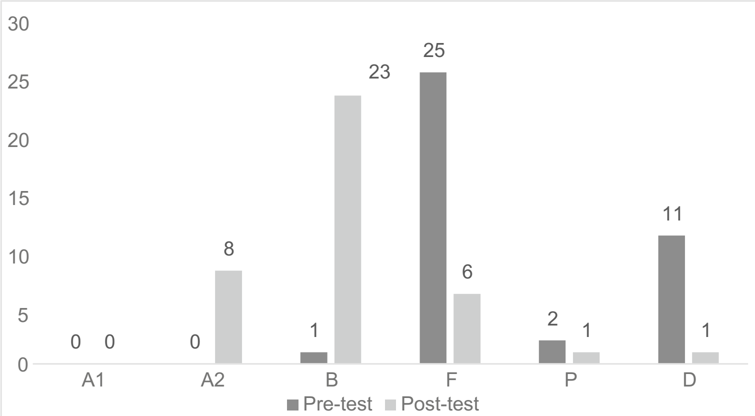


Fig. 9 Frequencies of the students' justification categories in question 8 (A1, correct/complete energy representation; A2, correct/incomplete energy representation; B, incorrect energy representation; F, phenomenological/tautological representation; P, pre-energy representation; D, no justification/ignorance)

A significant number of students are aware of the operation of a domestic energy meter. This is a positive indication, because it suggests that the introduction of activities related to the measurement of energy with an energy meter, regardless of whether it is restrained in the laboratory or used in everyday life, can be (and in fact has been) accomplished without substantial difficulties during the proposed teaching intervention. At the same time though, it seems that most students are not familiar with the precise use of the energy meter. For both questions, the post-test results imply that the students' mental representations shift from qualitative (mainly deriving from the justification category F) to quantitative forms. Nevertheless, as we have observed in the paired questions 5 and 6, in the question involving the concept of energy supply/power, the shift towards justification categories A is less significant than in the question involving the concept of amount of energy. In other words, the

Table 5 Wilcoxon test for the pre-test and post-test questions

Question	Shift			Wilcoxon test
	Progress post-test > pre-test (N)	Stagnation post-test = pre-test (N)	Retrogression post-test < pre-test (N)	
Question 1	35	4	0	($z = -5.31$, $p = 0.01$)
Question 2	31	8	0	($z = -5.29$, $p = 0.01$)
Question 3	24	15	0	($z = -4.49$, $p = 0.01$)
Question 4	15	24	0	($z = -3.50$, $p = 0.01$)
Question 5	24	15	0	($z = -4.52$, $p = 0.01$)
Question 6	20	18	1	($z = -3.99$, $p = 0.01$)
Question 7	31	7	1	($z = -5.02$, $p = 0.01$)
Question 8	20	19	0	($z = -4.13$, $p = 0.01$)

hypothesis we posed has been confirmed, since the students were not able to differentiate between the concepts of energy and power.

Here follow indicative justifications. In regard to question 7, on the pre-test, a student (B.3) claims that "The number will grow higher during the first two hours because there are ten lamps, while during the last two hours they will not grow as much because there are half [lamps]," but he alters his view on the post-test as he states that "I chose (a) because when I have ten lamps on they will receive more energy, so the numbers will faster grow higher. The Electric Company's meter counts the energy that the lamps receive, namely the Joules." In question 8 though, the same student shifts from the view "It will rotate faster because there are more devices" (pre-test) to the view "I believe that (a) is what will happen because ten lamps will receive more energy in two hours and the Electric Company's meter will measure the energy that the lamps receive in two hours" (post-test).

The Students' Cognitive Progress

By performing a Wilcoxon test for the justifications that the students provided in the pre-test and post-test questionnaires for each question separately, we received the results depicted in Table 5. In this table, the term *progress* corresponds to the students' advancement in their performance regarding the adequacy of their justifications (higher post-test values—Table 4). The term *stagnation* corresponds to the maintenance of the students' performance in both tests. Finally, the term *retrogression* corresponds to the decline in the students' performance (lower post-test values—Table 4).

This test shows that there is a statistically significant shift in terms of adequacy for the vast majority of justifications provided by students, namely a shift from phenomenological or pre-energy mental representations to mental representations that are more compatible with the energy chain model, which was introduced within the previously described teaching intervention.

Discussion and Conclusions

In the present study, we attempted to verify that it is possible to design a teaching intervention for children 10–11 years old with the following objectives for the students: (a) to construct a *semi-quantitative* energy model in order to explain physical situations that occur in the school laboratory as well as in the social environment and (b) to realize that the use of this model is sufficient in order to discuss *social aspects* of the energy concept. More specifically, we tried to verify the existence of at least one conceptual model, the one of energy chains (Tiberghien & Megalakaki 1994; Koliopoulos & Ravanis 2000b) that is an appropriate didactic transposition of scientific knowledge to school knowledge for children of this age. This model seems to restore the compatibility between the knowledge provided and the students' causal reasoning, as expressed at this age (linear causal reasoning); this type of reasoning primarily constitutes an auxiliary tool in order for the students to construct some features of the model. In addition, this model can efficiently work within an educational environment that is characterized by, on the one hand, the *innovative* and, on the other hand, the *constructivist* framework for the teaching and learning.

Equivalent approaches with positive results at the primary education level, though few, have already been mentioned in the pertinent literature (Papadouris & Constantinou 2011; Colonnese et al. 2012). In these approaches, researchers have been predominantly interested in the qualitative aspect of energy. For example, Papadouris and Constantinou (2011) suggest an appropriate teaching intervention "for students in the age range 11–14, that introduces energy as an entity in a theoretical framework that provides an epistemologically appropriate context that lends meaning to energy and its various features (i.e. transfer, form conversion, conservation and degradation)" (p. 961). Colonnese et al. (2012) propose "an educational path that was developed for use with upper primary school pupils (10–11 years). Each step was intended to lead logically to the *discovery* of a new type of energy or to the exploration of the variables associated with a particular type. At each stage, there was an attempt to direct students' attention to the transformation of energy from one type to another. The idea of conservation was only hinted at (in a qualitative way), in an experiment late in the sequence in which an object bobs on the end of a spring. The intent was to lay the groundwork for a more quantitative treatment of energy in later studies in middle and high school" (p. 27). On the other hand, the construction of a quantitative mental representation of energy is a *rare research finding* for children 10–11 years old. Lacy et al. (2014) mention that the fifth graders, after a brief teaching intervention, are able to formulate quantitative energy conceptions ("… most students could describe changes in terms of (a) no, more, or less energy as a property of objects and systems, (b) different manifestations or forms of energy (and exhibited beginning understanding of energy in all its forms as a unitary thing), (c) energy transfer in terms of gains and losses in pairs or multiples …", p. 261). From our point of view, the present research is an extension of the abovementioned works, since we investigate whether our teaching intervention leads the students of this age towards the construction of an initially well-established quantitative conception of the energy concept.

Our teaching intervention confirms the appropriateness of the qualitative features of the proposed conceptual model and, more importantly, introduces the quantitative dimension of energy in a manner that leads students towards the construction of an undifferentiated "amount of energy" concept. The concept of the "amount of energy" appears to be constructed by the introduction of (a) activities that lead to the formation of quantitative nature's causal relations (Anderson 1986), (b) schematic representations of the energy chain model that reflect the energy transfer, and (c) activities for the measurement of electric energy with the assistance of a Joulemeter and domestic energy meters. More specifically, the students' construction of the quantitative dimension of the energy concept seems to be accomplished through the introduction of the broad sections of "Energy as quantity" and "Measuring energy" (Table 1). The activities that are included in the section "Energy as quantity" lead the students towards the activation of a cognitive structure with quantitative features, which is referred to as "transitive thought" (Piaget & Garcia 1971, 1983; Ravanis et al. 2002). This structure contains an intermediate causal factor that links the initial cause to the final result of a natural phenomenon. The section "Measuring energy" reinforces this structure through the activities that involve the measurement of energy.

We are not aware of another research for children of this age that connects the quantitative mental representations of energy with activities on the measurement of energy. Nevertheless, the results demonstrate that the children fail to conceive the differentiation between the concepts of "energy quantity" and "energy supply" ("power"). Such a result appears to be normal for the children of this age, since the relevant research shows that this differentiation is challenging for older students as well (Bécu-Robinault 1997). Further research is needed in order to ascertain whether this result is due to the young students' cognitive structure (i.e., inability to handle the concept of "rate") or because of possible insufficiencies in the content of our teaching sequence.

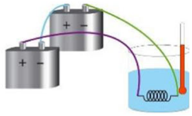
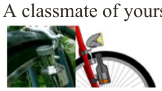
Our original hypothesis seems to be also confirmed regarding the students' constructions of some social uses of the energy concept. Lijnse (1990) has put a similar research question many years ago: "Does a theoretical understanding of energy also have a direct significance for coping with energy in one's life-world?" (p. 579). As it appears, the introduction of a domestic phenomenological framework can lead children of this age group to use the semi-quantitative form of the energy chain model in order to interpret and discuss the phenomena that take place not only at the school environment but in a household as well. This result seems to derive from the activities that are included in sections 9–12 (Table 1). These particular activities refer to the energy measurement with the use of the domestic energy meter and the issue of energy saving. The prime objective of these activities was for the students to connect the concept of energy saving (cultural component) to the conceptual component of school knowledge about energy and, in addition, a minor goal was to cultivate positive attitudes towards the energy saving at home. The results indicate that the students seem to (a) realize that the "amounts of energy" are transferred simultaneously to several house appliances (Fig. 3a, b) and (b) be able to attribute meaning to the quantitative data that relate to the domestic energy meter. These findings are significant since several researchers have noted a certain difficulty in the connection between the energy concept and social issues, due to the complexity of the conceptual framework usually involved in the discussion of such matters (Besson & De Ambrosis 2014). For example, Solomon (1985) claims that younger children face difficulties in encountering social uses of the concept owing to the multifaceted, large-scaled technological systems involved. Such difficulties need to be addressed in a special way. Sissamberi and Koliopoulos (2015), for example, in order to deal with this issue, designed a specific teaching sequence for 11–12-year-old children, based on the energy chain model that is also proposed in this study, but related to large-scale electricity generation systems (thermoelectric power plants, hydroelectric power plants, wind farms, photovoltaic farms).

The pre-experimental scheme we followed does not allow us to ascertain beyond any doubt that the described cognitive progress is solely derived from the context of the teaching intervention. However, we are allowed to make this assumption, taking into consideration that we cautiously attempted to control factors such as the instructor or the initial uniformity of the alternative mental representations of the students that took part in the teaching intervention. Our hypothesis remains to be confirmed by a real experimental procedure (Cohen et al. 2011). Additionally, our research group is presently working in this direction.

Appendix

Table 6 The questionnaire

The questionnaire

Unit	Question	Question topic	Expected cognitive outcome
1st	1	*If we connected a battery with a lamp, the lamp would turn on. If we connected a battery with a small fan (which consists of a small engine that has a small propeller at the edge), then the small fan would start turning around.* Can you provide a *common* explanation for *both* phenomena (lamp switching on and movement of the small fan)? Yes ☐ No ☐ I don't know ☐ If yes, please explain. If no, write why not.	Correct and complete presentation of the qualitative conceptual features of the energy chain model
	2	 The image presents a battery connected to a small heater, which is placed in a container full of water. As time goes by, the water gets hotter. If we gave you three tabs named HEATER, BATTERY and WATER and asked you to put them in an order, what would that order be? (α) WATER → BATTERY → HEATER ☐ (β) BATTERY → HEATER → WATER ☐ (γ) HEATER → WATER → BATTERY ☐ (δ) I don't know ☐ Please justify your answer.	
2nd	3	*If we connected two batteries with the lamp of question 1 for two minutes, the lamp would light more brightly (see Image a). If we connected two batteries with the small heater of question 2 for two minutes, the water would get even hotter (see Image b).*  Image a  Image b Could you provide a common explanation for both cases on the reason why the lamp would light more brightly and the water would get even hotter during the two-minute period? Yes ☐ No ☐ I don't know ☐ If yes, please explain. If no, write why not.	Correct and complete presentation of the quantitative conceptual features of the energy chain model
	4	IN CASE YOU ALREADY KNOW WHAT A **DYNAMO** IS, PLEASE SKIP THE FOLLOWING TEXT AND GO DIRECTLY TO THE QUESTION. *Many bicycles have a light, which doesn't work with a battery but by a device called 'dynamo'. This device is connected to the light through cables. The light turns on whenever the dynamo is rotated, because it touches the wheel of the bicycle that spins.* A classmate of yours rides a bicycle and realizes that he/she is  Image 4 obliged to pedal harder whenever the wheel touches the dynamo (with the help of which the bicycle's light turns on) (see Image). Explain why does this happen.	
3rd	5	If we connected a battery to a lamp, the lamp would turn on. If we gave a closer look at the lamp, we would see that there is a paper with t he indication **10W** (Watt). What does the phrase	Use of the terms 'Joule' and 'Watt' in the context of the energy

		'The lamp is 10W' means?	chain model
	6	*If we connected a battery with the lamp for two minutes, the lamp would turn on. If we connected a battery with a small heater for two minutes, the water would get hotter.* What is the meaning of the following phrase? 'During these two minutes I have spent 150J (Joule) for keeping the lamp turned on and 700J (Joule) for the water heating".	
4th	7	 *In front of every house, the Electric Company has placed a device that is called 'energy meter' (see Image). Whenever the electric devices we use at home (for example the lamps, the fan, the cooker etc.) are on, the disc of the meter rotates. Also, the numbers on the top of the meter grow higher (like the speedometer while we drive a car).* Let us suppose that inside the house ten lamps are turned on for two hours. Afterwards, for the next two hours we turn off half of the lamps. What would happen then? (a) During the first two hours the numbers would be growing higher in comparison to the next two hours. (b) During the first two hours the numbers would be growing just as much as during the next two hours. (c) During the first two hours the numbers would be growing less high in comparison to the next two hours. (d) I don't know what would happen. Justify your answer.	
	8	Let us suppose that inside the house ten lamps are turned on for two hours. Afterwards, for the next two hours we turn off half of the lamps. What would happen then? (a) During the first two hours the disc of the meter would rotate faster in comparison to the next two hours. (b) During the first two hours the disc of the meter would rotate just as much as during the next two hours. (c) During the first two hours the disc of the meter would rotate slower in comparison to the next two hours. (d) I don't know what would happen. Justify your answer.	Application of a correct and complete presentation of the energy chain model in real life situations
	9 (post-test only)	Let us suppose that we have simultaneously turned on a lamp, a cooker and a fan for a two-hour period. During this period, the energy meter records the amounts of energy transferred at the house. Draw any figure you like in order to show the energy transfer while the three devices (lamp, cooker and fan) are turned on at the same time.	

References

Agabra, J., Gautherin, J., Lemeignan, G., Pezet, R., & Verlhac, M. (1979). *Sciences Physiques. Collection Libres Parcours*. Paris: Hachette.

Anderson, A. (1986). The experiential gestalt of causation: a common core to pupils' preconceptions in science. *European Journal of Science Education, 8*(2), 155–172.

Astolfi, J.-P. (1993). Trois paradigmes pour la recherche en didactique. *Revue Française de Pédagogie, 103*, 5–18.

Bächtold, M. (2017). How should energy be defined throughout schooling? *Research in Science Education.* https://doi.org/10.1007/s11165-016-9571-5.

Baehr, H.-D. (1978). *Thermodynamik*. Berlin: Springer-Verlag.

Bécu-Robinault, K. (1997). Activités de modélisation des élèves en situation de travaux pratiques traditionnels : introduction expérimentale du concept de puissance. *Didaskalia, 11*, 7–37.

Besson, U., & De Ambrosis, A. (2014). Teaching energy concepts by working on themes of cultural and environmental value. *Science & Education, 23*(6), 1309–1338.

Chen, R. F., Eisenkraft, A., Fortus, D., Krajcik, J., Neumann, K., Nordine, J., & Scheff, A. (2014). *Teaching and learning of energy in K-12 education*. Cham: Springer International Publishing.

Chevallard, Y. (1985). *La transposition didactique*. Grenoble: La Pensée Sauvage.

CLISP. (1987). *Approaches to teaching energy*. Internal report: University of Leeds.

Cohen, L., Manion, L., & Morrison, K. (2011). *Research methods in education* (7th ed.). London: Routledge / Falmer, Taylor & Francis Group.

Colonnese, D., Heron, P., Michelini, M., Santi, L., & Stefanel, A. (2012). A vertical pathway for teaching and learning the energy concept. *Review of Science, Mathematics and ICT Education, 6*(1), 21–50.

Domenech, J., Gil-Perez, D., Gras-Marti, A., Martinez-Torregrosa, J., Guisasola, G., Salinas, J., Trumper, R., Valdes, P., & Vilches, A. (2007). Teaching of energy issues: a debate proposal for a global reorientation. *Science & Education, 16*(1), 43–64.

Driver, R., & Millar, R. (1986). *Energy matters*. University of Leeds.

Falk, G., & Hermann, F. (1981). *Neue Physik, Das energiebuch*. Hannover: Schroedel.

Falk, G., Hermann, F., & Bruno Schmid, G. (1983). Energy forms or energy carriers? *American Journal of Physics, 51*(12), 1074–1077.

Field, A. (2009). *Discovering statistics using SPSS*. Sage.

Haber-Schaim, U. (1983). *Energy*. New Jersey: Prentice-Hall, Inc..

Halbwachs, F. (1971). Causalité linéaire et causalité circulaire en physique. In M. Bunge, F. Halbwachs, T. Kuhn, J. Piaget, & L. Rosenfeld (Eds.), Les théories de la causalité. Paris: Presses Universitaires de France.

Hammer, D., Goldberg, F., & Fargason, S. (2012). A vertical pathway for teaching and learning the energy concept. *Review of Science, Mathematics and ICT Education, 6*(1), 51–72.

Hodson, D. (1990). A critical look at practical work in school science. *School Science Review, 71*(256), 33–40.

Koliopoulos, D., & Tiberghien, A. (1986). Elements d'une bibliographie concernant l'enseignement de l'energie au niveau des colleges. *Aster, Institut National de Recherche Pédagogique, 2*, 167–178.

Koliopoulos, D., & Ravanis, K. (1998). L'enseignement de l'energie au college vu par les enseignants. Grille d'analyse de leurs conceptions. *Aster, Institut National de Recherche Pédagogique, 26*, 165–182.Please check captured journal title for Koliopoulos & Ravanis (1998) and Koliopoulos & Ravanis (2000a) if correct.–>

Koliopoulos, D., & Ravanis, K. (2000a). Reflexions methodologiques sur la formation d'une culture concernant le concept d'energie a travers l'education formelle. *Revue de Recherches en Éducation : SPIRALE, 26*, 73–86.

Koliopoulos, D., & Ravanis, K. (2000b). Elaboration et evaluation du contenu conceptuel d'un programme constructiviste concernant l'approche energetique des phenomenes mecaniques. *Didaskalia, 16*, 33–56.

Koliopoulos, D., & Ravanis, K. (2001). Didactic implications resulting from students' ideas about energy: an approach to mechanical, thermal and electrical phenomena. *Themes in Education, 2*(2-3), 161–173.

Koliopoulos, D., & Constantinou, C. (2005). The pendulum as presented in school science text-books of Greece and Cyprus. *Science & Education, 14*(1), 59–73.

Koliopoulos, D. (2006). *Issues in Science Education*. Athens: Metaixmio [In Greek].

Koliopoulos, D., & Argyropoulou, M. (2011). Constructing qualitative energy concepts in a formal educational context with 6–7-year-old students. *Review of Science, Mathematics and ICT Education, 5*(1), 63–80.

Koliopoulos, D., Aduriz-Bravo, A., & Ravanis, K. (2012). El «analisis del contenido conceptual» de los curriculos y programas de ciencias: una posible herramienta de mediacion entre la didactica y la ensenanza de las ciencias. *Enseñanza de las Ciencias, 29*(3), 315–324.

Koliopoulos, D., & Constantinou, C. (2012). Energy in education. *Review of Science, Mathematics and ICT Education, 6*(1), 3–6.

Koliopoulos, D. (2014). Is it possible to teach energy in preschool education? In F. Tasar (Ed.), *Proceedings of the WCPE Conference* (pp. 457–461). Ankara: Gazi Universitesi.

Koulaidis, V., Dimopoulos, K., & Sklaveniti, S. (2002). Analyzing the texts of science and technology: school science textbooks and daily press articles in the public domain. In M. Kalantzis, G. Varnava-Skoura, & B. Cope (Eds.), *Learning for the future* (pp. 209–240). Sydney: Common Ground.

Kuhn, T. (1977). Energy conservation as an example of simultaneous discovery. In T. Kuhn (Ed.), *The essential tension* (pp. 66–104). Chicago: The University of Chicago Press.

Lacy, S., Tobin, R. G., Wiser, M., & Crissman, S. (2014). Looking through the energy lens: a proposed learning progression for energy in grades 3–5. In R. F. Chen, A. Eisenkraft, D. Fortus, J. Krajcik, K. Neumann, J. Nordine, & A. Scheff (Eds.), *Teaching and learning of energy in K-12 education* (pp. 246–265). New York: Springer.

Lemeignan, G., & Weil-Barais, A. (1994). A developmental approach to cognitive change in mechanics. *International Journal of Science Education, 16*(1), 99–120.

Lijnse, P. (1990). Energy between the life-world of pupils and the world of physics. *Science Education, 74*(5), 571–583.

Martinand, J.-L. (1986). *Connaitre et transformer la matière*. Berne: Peter Lang.

Meheut, M., & Psillos, D. (2004). Teaching-leaning sequences: aims and tools for science education research. *International Journal of Science Education, 26*(5), 515–535.

Meli, K., Koliopoulos, D., Lavidas, K., & Papalexiou, G. (2016). Upper secondary school students' understanding of adiabatic compression. *Review of Science, Mathematics and ICT Education, 10*(2), 131–147.

Millar, R. (1989). Constructivism criticisms. *International Journal of Science Education, 11*, 587–596.

Millar, R. (2005). *Teaching about energy (Research Paper 2005/11)*. York: Department of Educational Studies, University of York.

Papadouris, N., & Constantinou, C. P. (2011). A philosophically informed teaching proposal on the topic of energy for students aged 11–14. Science & Education, 20(10), 961–997. 635

Piaget, J., & Garcia, R. (1971). *Les explications causales*. Paris: PUF.

Piaget, J., & Garcia, R. (1983). *Psychogenèse et histoire des sciences*. Paris: Flammarion.

Ravanis, K., Papamichael, Y., & Koulaidis, V. (2002). Social marking and conceptual change: the conception of light for ten-year old. Journal of Science Education, 3(1), 15–18. 639

Rozier, S., & Viennot, L. (1991). Students' reasoning in thermodynamics. *International Journal of Science Education, 13*(2), 159–170.

Ruthven, K., Laborde, C., Leach, J., & Tiberghien, A. (2009). Design tools in didactical research: instrumenting the epistemological and cognitive aspects of the design of teaching sequences. *Educational Researcher, 38*(5), 329–342.

Sissamberi, N. & Author 2, (2015).Please provide comple bibliographic details for this reference.–>

Solomon, J. (1985). Learning and evaluation: a study of school children's views on the social uses of energy. *Social Studies of Science, 15*, 343–371.

Solomon, J. (1994). The rise and fall of constructivism. *Studies in Science Education, 23*(1), 1–19.

Tiberghien, A. (1996). Construction of prototypical situations in teaching the energy concept. In G. Welford, J. Osborne, & P. Scott (Eds.), *Research in science education in Europe. Current issues and themes* (pp. 100–114). London: The Falmer Press.

Tiberghien, A. (1997). Learning and teaching: differentiation and relation. *Research in Science Education, 27*(3), 359–382.

Tiberghien, A. (2000). Designing teaching situations in the secondary school. In R. Millar, J. Leach, & J. Osborne (Eds.), *Improving science education: the contribution of research* (pp. 27–47). Buckingham: Open University Press.

Tiberghien, A., & Megalakaki, O. (1995). Characterization of a modelling activity for a first qualitative approach to the energy concept. *European Journal of Psychology of Education, 10*(4), 369–383.

Viglietta, V. (1990). A more 'efficient' approach to energy teaching. *International Journal of Science Education, 12*(5), 491–500.

Zemansky, M. W., & Dittman, R. H. (1987). *Heat and thermodynamics*. New York: McGraw-Hill.