A semiotic approach for the teaching of energy: linking mechanical work and heat with the world of objects and events

PANAGIOTIS PANTIDOS[1], DAMIEN GIVRY[2]

[1]Department of Early Childhood Education
National and Kapodistrian University of Athens
Greece
ppantidos@ecd.uoa.gr

[2]Aix Marseille University
UR 4671 ADEF, Marseille
France
damien.givry@univ-amu.fr

Abstract

In this study an effort is made to provide links between the world of physics (theoretical) model about energy transfer with the world of objects and events. Taking into account a holistic approach on energy based on conservation of energy principle and a semiotic approach based on the multimodality of teaching, it was investigated whether a 'no contact, contact plus change' pattern can signify in the material world the separation and the interaction between the physical systems and the changes within the systems. An analysis of a teacher's actions from a physics lesson and a physics textbook concerning mechanical work and heat as mechanisms of energy transfer was made, identifying the no contact, contact + change pattern in speech, written text, bodily acts and inscriptions. It was shown that this semiotic schema has the potential to transfer the physics model about mechanical work and heat to the world of objects and events avoiding ambiguities that create conceptual blending between transformation and transfer of energy. In addition, illustrating the idea of change by movement for mechanical work (position change) and by haptic contact or different colours for heat (temperature change) might be of great importance in teaching activities about transfer of energy.

KEYWORDS
Transfer of energy, mechanical work, heat, semiotic actions, inscriptions

RÉSUMÉ
Cette recherche propose d'étudier les liens entre le monde des théories et des modèles avec celui des objets et des événements pour appréhender différemment le concept de transfert d'énergie. À partir d'une approche holistique de l'énergie basée sur le principe de conservation complétée par une approche sémiotique basée sur l'enseignement multimodal, nous proposons d'étudier comment un modèle sémiotique (nommé) " sans contact, contact + changement " peut aider à illustrer dans le monde matériel la séparation entre deux systèmes physiques et l'interaction entre eux ainsi que les changements au sein de ces derniers. Une analyse des actions d'un enseignant à partir d'une leçon de physique et d'un manuel de physique concernant le travail mécanique et la chaleur en tant que mécanismes de transfert d'énergie a été faite, cherchant à identifier le modèle sémiotique "sans contact, contact + changement" dans la parole, les gestes, les mouvements corporels, ainsi que les textes écrits, et les inscriptions. Il a été montré que ce schéma sémiotique a le potentiel de transférer le modèle physique du travail mécanique et de la chaleur vers le monde des objets et des événements en évitant certaines ambiguïtés qui peuvent créer une confusion conceptuelle entre la transformation et le transfert d'énergie. En outre, illustrer l'idée de changement par le mouvement pour le travail mécanique (changement de position) et par contact haptique ou différentes couleurs pour la chaleur (changement de température) pourrait être d'une grande importance dans les activités d'enseignement sur le transfert d'énergie.

MOTS-CLÉS
Transfert d'énergie, travail mécanique, chaleur, actions sémiotiques, inscriptions

INTRODUCTION

Many researchers in science education recognise energy as a fundamental concept in teaching science in all levels of schooling acknowledging also the difficulty to be understood due to its abstractive character (Eisenkraft et al., 2014; Lee & Liu, 2010; Millar, 2005; Tang, Tan, & Yeo, 2011; Warren, 1982). Students often have misconceptions between force and energy or heat and temperature whereas in many cases, even in textbooks, there is not a clear distinction between forms of energy and mechanisms of energy transfer (Givry & Pantidos 2015; Kaliampos, 2015; Lewis & Linn, 1994; Watts, 1983). Clear definition of the system(s), use of proper oral language and schematic representations, use conservation energy equation in problem solving and clarification the concept of work could be the most important implications for the teaching of energy (Jewett, 2008; Koliopoulos & Argyropoulou, 2012; Scherr et al., 2012). Bächtold (2018) supports the need for providing to students with the conservation of energy principle together with a definition on energy as a concept that enables the idea of 'change'. Generally, it is suggested the physics teachers to adopt a global approach about energy in order students to understand physical processes and solve problems (Doménech et al., 2007; Duit, 1987; Jewett, 2008).

In our previous studies we showed through the analysis of a school textbook and a teacher's performance concerning the concept of energy that ambiguities appear in representing the conservation energy principle in semiotic terms (Givry & Pantidos, 2015). In the textbook photos from everyday life, graphs, drawings, diagrams, equations as well as actions including bodily performance could convey ambiguities by no separating the systems and by no making distinction between transfer (from one system to another) and transformation of energy (within a system). For the representation of mechanical work, it was also shown how these ambiguities could be overcome by adopting a "no contact, contact plus displacement" semiotic schema (Pantidos & Givry, 2016).

The current paper adopts a socio-constructivist framework (Fragkiadaki, Fleer & Ravanis, 2019; Leontiev, 1978) and combines the approach of modelling activity (Tiberghien, 2000) with the multimodal view on teaching and learning (Givry & Roth, 2006; Givry & Pantidos, 2012; Kress et al., 2001; Pantidos et al., 2008; Pantidos, 2019). Starting from Tiberghien's modelling activity approach regarding aspects of energy concept, we try to define the conditions which make links between the world of model and the world of objects and events. For the world of model, we use the *physics* approach based on energy chain perspective to define energy whereas for the world of objects and events the *semiotic* approach based on the multimodality of teaching.

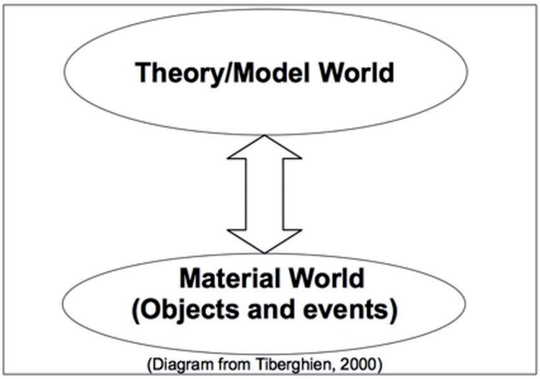
Theoretical framework

According to modelling activity approach the teaching of any concept is an effort of constructing links between the world of objects/events and the world of theory/model (Tiberghien, 1996, 2000; Vince & Tiberghien, 2012) (Figure 1).

Tiberghien (2000, p. 2) argues that "the world of objects and events refers to all observable aspects of the material world, whereas on the other hand, the world of theories and models refers to theoretical aspects and elements of the constructed model of the material situations, in terms of various principles, parameters or quantities"

More specifically, Tiberghien, Vince & Gaidioz (2009, p. 2285) consider that "the world 'theories and models' includes theory and modelling elements, allowing us to relate theory to the observed and selected event or measurement readings [...]. The world 'objects and events' includes the material (inanimate) world and the observation and description of objects and events including measurement readings".

FIGURE 1



Modelling activity approach makes links between the world of theory/model and the world of objects and events (Tiberghien, 2000)

These previous researches consider the modelling activity approach as common basis to analyse the knowledge to be taught, the knowledge that is actually taught and students' knowledge (included their everyday knowledge which can or not overlap with the taught physics theory/model). The current study focuses on the knowledge which is actually taught and concerns the concept of energy transfer as it is communicated by a teacher and a textbook. Thus, the modelling activity approach about the knowledge which is actually taught, we discuss for the energy transfer: (a) the world of theory and model in terms of the physics model of energy chain, (b) the world of objects and events using semiotic resources contained in talk, gestures, setting, text and inscriptions based on the multimodal approach about teaching, and (c) the three conditions of a 'no contact, contact plus change' pattern which provide the link of these two worlds (Pantidos & Givry, 2016).

Physics model about energy in the world of theories and models

The physics model concerning energy, which is presented here, is based on energy conservation principle combined with a modified Rakine's definition about energy that connects energy with the idea of change (Bächtold, 2018). In that sense energy is connected with the changes in physical entities indicating for instance variation in the speed or in the temperature of a body, emission of light, change in its physical state, or a mechanical deformation. Putting together the idea of change with the concepts of system, forms and transfer, the conservation energy principle adopts a conceptual character that avoids to perceive it as an equation with exclusively computational use.

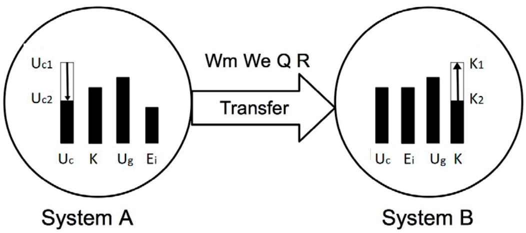
System, forms and transfer of energy are major concepts in a physics approach on energy (Jewett, 2008). System can be understood as a set of components forming and integrating a whole, which can be delimited by thinking. An isolated system could be defined by an arrangement for which there is no transfer of matter and energy across the boundary. A non-isolated system experiences transfer of energy across the boundary through one or more mechanisms (i.e., mechanic or electrical work, heat or radiation). The conservation of energy equation is:

$$\Delta K + \Delta U + \Delta E_i = W_m + W_e + Q + R$$

The left side of the equation shows three forms of energy which can be stored in a system. Kinetic energy (K), potential energy (U) and internal energy (E_i). Potential energy includes gravitational (U_g), electric (U_e) and elastic (U_{el}) energy. Jewett (2008) includes also in potential energy the chemical potential energy of fuel or explosives and biological potential energy from eaten meals. In the current article the authors specify the two last forms of potential energy as chemical energy (U_c). Internal energy (E_i) is connected with the motion of the molecules as well as the bond energy between molecules associated with the change in the phases of the system (ibid.)

We can calculate the change in the total energy stored in a system by adding the individual changes for each form of energy. The whole, internal, change within a system is called transformation. On the right side is the total amount of energy that crosses the boundary of the system expressed as the sum of the transfer of energy from a system (A) to a system (B). Mechanical work (W_m), electrical work (W_e), heat (Q) and radiation (R) are the processes of energy transfer. The conservation of energy can be represented by the following diagram (Figure 2) which is based on previous researches on understanding energy in terms of energy chains (Delegkos & Koliopoulos, 2020; Koliopoulos & Ravanis, 2000; Lemeignan & Weil-Barais, 1994; Meli et al., 2016; Tiberghien, 1996).

FIGURE 2



Model of energy illustrating system, forms and transfer of energy (Givry & Pantidos, 2015)

This diagram represents a model of energy which shows the transformations of some forms of energy and the four types of transfer of energy between the two systems [i.e. mechanical work (W_m), electrical work (W_e), heat (Q) and (R) radiation]. For example, chemical energy (U_c) decreases into the system A and kinetic energy (K) increases into the system B. In this kind of energy chain more than two systems and four forms of energy can be used for complex situations. In the present study the model of energy is discussed for two specific transfers; mechanical work and heat. In Figure 2, which refers to two systems, the symbol => chosen instead of ↔ although the second one illustrates interactions between non-isolated systems. However, we think that the => sign denotes more clearly the idea that 'an agent (system A) *causes* through transfers, transformations in a system B'.

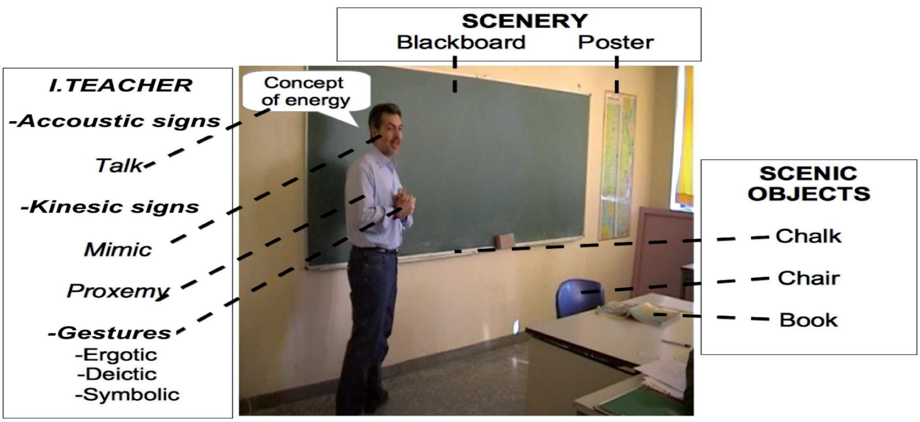
Semiotic resources used to describe the world of objects and events

The semiotic approach adopted in the current study is based on researches on multimodality (Givry & Pantidos, 2012; Kress et al., 2001) and inscriptions (Duval, 2006; Lemke, 1998; Pozzer-Ardenghi, 2009).

Oral language: talk, body and setting

In the context of a multimodal approach with respect to science teaching, meaning is distributed among various modalities which are rhetorically orchestrated and essentially raised by teacher's and students' actions (Kress et al., 2001). A typical semiotic approach in science teaching focuses on specific semiotic resources contained into oral communication (Givry & Pantidos, 2012): (a) acoustic signs (linguistic and paralinguistic), (b) kinesic signs (gestural, mimic, proxemics) and (c) spatial signs (scenery, scenic objects) (Figure 3).

FIGURE 3

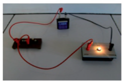
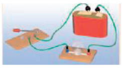
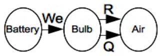
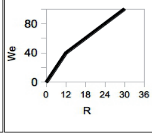


Teacher makes meaning interplaying talk, body and setting

Written language: inscriptions and text

This study accepts also the idea that text and inscriptions such as photographs, drawings, diagrams, graphs, tables and equations consist of sign vehicles assigning meaning to scientific concepts. Each visual mode can describe in a specific way aspects of energy (Figure 4).

FIGURE 4

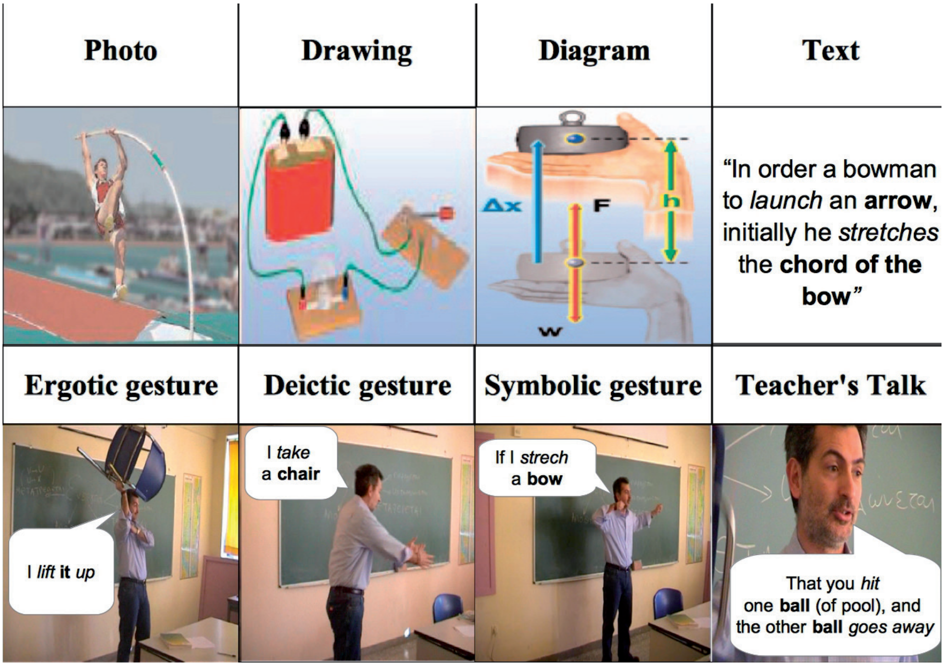
Photographs	Drawings	Diagrams	Graphs	Tables	Equations
				We (W) | R 40 | 12 60 | 18 80 | 24	$\Delta Ec = We = Q + R$

Transfer of energy is expressed by various inscriptions

From the concrete representations such as photographs and drawings to the more abstract forms such as diagrams, graphs, tables and equations, written text can joint all these together presenting a continuum (Givry & Andreucci, 2015; Pozzer-Ardenghi & Roth, 2010).

The world of objects and events can be described by written and oral language. Figure 5 illustrates how text and inscriptions from a textbook and talk, body and setting from a teacher's performance can describe the world of *objects* and *events*. The photo shows "an athlete *deforming* (event) a *pole* (object)", the drawing depicts "an open electrical circuit with a *light switch* (object) *open* (event)", the diagram exemplifies how a *body* (object) *goes up* (event) to a specific height. The text describes several objects (*arrow and chord of a bow*) and events (*launching* and *stretching*). In the same way, it is possible to illustrate objects and events in oral communication. Thus, teacher shows with: (i) talk and ergotic gesture how he *lifts up* (event) a *chair* (object), (ii) talk and deictic gesture how he *takes* (event) a *chair* (object), (iii) talk and iconic gesture how he *stretches* (event) a *bow* (object), and (iv) talk alone that a pool *ball* (object) *goes away* (event) when somebody *hits* (event) another *ball* (object).

FIGURE 5

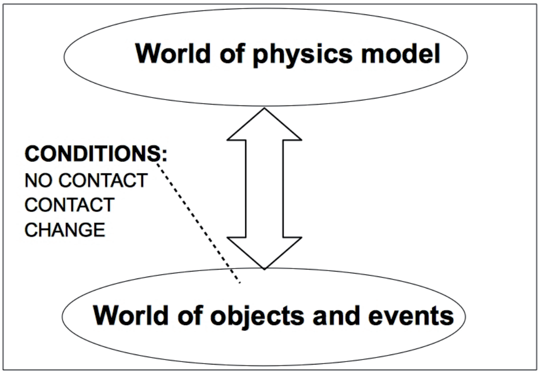


Examples of inscriptions, text, gestures and talk which describe objects and events

Conditions that make links between the two worlds

In previous researches (Givry & Pantidos, 2012, 2015; Pantidos & Givry, 2016) we defined the three conditions of no contact, contact and displacement as a pattern that helps convey the concept of mechanical work from the world of theory/model to the world of objects and events. In the current study we still use the idea of making conditions in terms of actual knowledge that connects these two worlds. Extending this to heat, as a mechanism also of energy transfer, we propose both for mechanical work and heat the schema of *no contact, contact, change* (Figure 6). The idea of change seems to be suitable for approaching mechanical work and heat as mechanisms of energy transfer since it helps describe what is happening within the systems that interact. Due to the energy transfer there are changes within the system that gives energy and within the system that receives energy. Also, change is a common observable situation in everyday life actions in the world of objects and events.

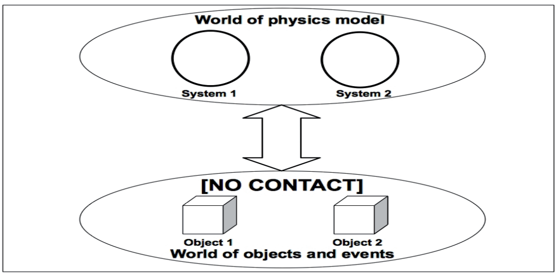
FIGURE 6



The three conditions in the world of objects and events allowing to link it with the world of physics model

The initial step applying the model of energy is to define clearly the systems (at least two). To the aim of avoiding ambiguities created by the choice of the systems (Givry & Pantidos, 2015), we propose first the *no contact* condition between the objects which represent the systems. Considering that each system symbolically corresponds to one object then the objects/systems has not to be in contact to each other. It should be noted that *system* refers to thermodynamic system and therefore *object* of the model in Figure 7, but also in the subsequent Figures, has an extended use. Actually, the idea of the object in the semiotic model does not explicitly refers to one entity but an object can contain more than one entities. For example, in an action where a man kicks a ball, system 1 may be the object man, while system 2 may be the object that is notionally created by the ball and the Earth together. Thus, the model can be applied in cases a system corresponds to a set of components. Generally, the no contact condition provides a clear conceptual definition for each of the systems (Figure 7).

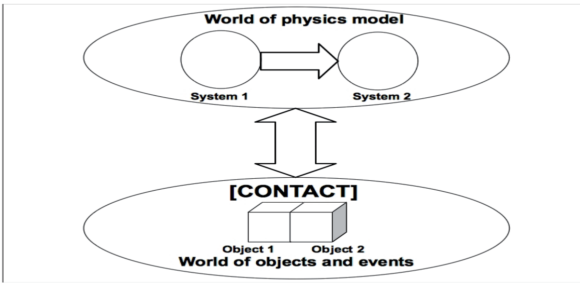
FIGURE 7



First condition to identify two systems: no contact between the objects

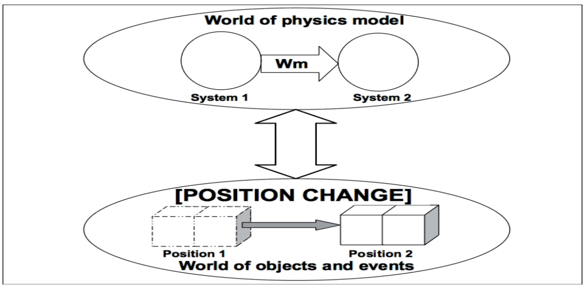
In the second step, which appears since the two systems (at least) are clearly separated, we need to describe the transfer through *contact* between the objects. Depending on the mechanism of transfer (i.e., mechanical work or heat) we need to identify in the material world the type of *change* (i.e., in the position or in the temperature correspondingly). Hence, mechanical work can be represented through a perceptual *contact* event between those objects which in the first step were in no contact (Figure 8). After the contact a *change* in the *position* of both objects indicates that energy is transferred from the object 1 to the object 2 (Figure 9). It should be mentioned that mechanical work as mechanism of energy transfer refers to external forces exerted to the non-isolated system B (also an equal in magnitude force is exerted in system A) which their (forces) points of applications are displaced. Actually, energy is transferred through mechanical work only when the engaged force displaces its point of application. In that sense, Figure 9 describes situations in which the two objects/systems move together (exerting force by contact to each other) for a time period indicating that the point of application of the force is displaced.

FIGURE 8



Second condition to identify transfer: contact between the objects

FIGURE 9

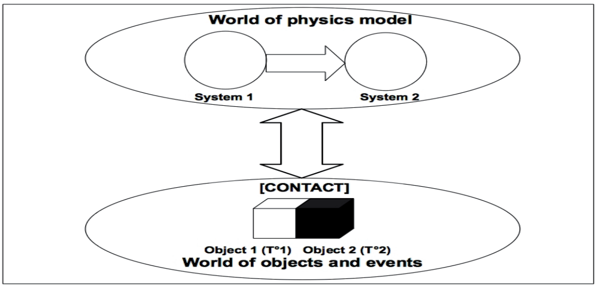


Third condition to identify the type of transfer (mechanical work): change in the position of the objects

Actually, position change refers to the world of objects and events and corresponds to the displacement of the external's force point of application. For example, when someone lifts up a book, the change in the position of the book corresponds to the displacement of the point of application of the exerted force from the hand to the book (see Figure 15). For the time period that hand/book were in contact, the hand transfers energy through mechanical work to the book. Figure 9 carries a symbolic value since it does not refer only to the position change in x-axis but to a position change in either direction.

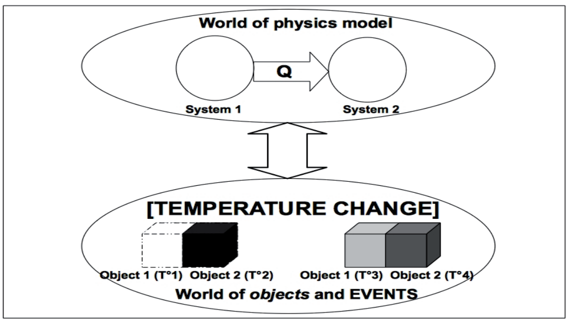
Correspondingly heat as a mechanism of energy transfer can be also identified in terms of a perceptual event through the *contact* between the objects plus a *change in the temperature* of the objects (Figure 10).

FIGURE 10



Second condition to identify the type of energy transfer (heat): contact between the objects

FIGURE 11



Third condition to identify the type of energy transfer (heat): change in the temperature of the objects 1 and 2

The change in the temperature can be applied only when the objects have not the same temperature before the contact ($T_1 \neq T_2$). Also the temperatures T_3, T_4 in Figure 11 refer to an interim state illustrating the ΔT (change) and not to the final thermal equilibrium state. Besides, what is described is related to thermal conduction rather than to thermal convection or thermal radiation. Thermal conduction is the mechanism when the "particles" of a body exchange their kinetic energy in the boundaries of their system with the "particles" of another body which are in the boundaries of the other system.

Research questions

Can we identify the conditions *no contact, contact, change* expressed through oral and written language, which link the world of physics model with the world of object and events, in the knowledge that is actually taught about transfer of energy?

More specifically:

- Can we identify these three conditions concerning *mechanical work* in semiotic resources expressed by *teacher's actions* and by the text and inscriptions in a *textbook*?
- Can we identify these three conditions concerning *heat* in semiotic resources expressed by *teacher's actions* and by the text and inscriptions in a *textbook*?

Methodological framework

Research design

To identify the three conditions in the worlds of teacher's actions and physics textbook a videotaped lesson and a textbook were analysed. More specifically: (a) a videotaped of 40 minutes lesson about energy of a Greek teacher in a classroom composed by 26 students (grade 9^{th}) and (b) a formal physics Greek textbook for 8^{th} grade (Antoniou et al., 2006). An attempt is made to recognise both for mechanical work and heat as mechanisms of energy transfer the no contact, contact + change pattern in teacher's actions (including speech, written text and bodily acts) and in the textbook (including diagrams, equations, tables, drawings, photos, text).

Data analysis

The data from the two sources was analysed by two researchers. Following the precepts of Interaction Analysis the researchers conducted tentative individual analysis (Jordan & Henderson, 1995). The two researchers after having held a series of meetings were comparing their results. When they disagreed a discussion was following until a common agreement to be established. Were this not the case the issue in question was excluded from the analysis. The data that was analysed concern meaningful teacher's actions (e.g., body movement) and extracts from the textbook (e.g., photo, text) that communicate: i) the separation of the two systems (*no contact*) and ii) the energy transfer from system A to system B (*contact + change in the position or temperature*). Data was analysed as it is described below:

a) transcription of the video and translation into English,
b) identification in the video teacher's speech and bodily actions that convey the no *contact, contact + change* pattern for mechanical work and heat,
d) identification in the video teacher's speech, written text in the blackboard and bodily actions that convey the no *contact, contact + change* pattern for mechanical work and heat,
d) identification in the textbook, text that conveys the *no contact, contact + change* pattern for mechanical work and heat. This was conducted only by the one researcher because the text was in the Greek language,
e) identification in the textbook photos, drawings and diagrams (including their captions and the text refer to them) that convey the *no contact, contact + change* pattern for mechanical work and heat.

Results

The *no contact* condition is presented first and then the *contact + change* condition both defined in teacher's actions and in the textbook.

No contact

The identification of the systems is represented by a *no contact* condition. The key point for this is the systems to be defined linguistically or visually as separated. Applying that both to inscriptions and human actions, each system could be corresponded to an object which contains one or more entities and each object (system) should not be in physical contact to the other. If this is not the case any physical contact between the objects (systems) creates ambiguities which may occur either in the teacher's actions (Figure 12) or in the inscriptions (Figure 13).

In Figure 12 it is the physical contact between the teacher and the bag or between the teacher and the 'bow' which does not allow a viewer to define which is (are) exactly the system(s). If teacher-bag or teacher-bow is perceived as one system, and the other is the Earth, then the discussion may focus on transformation of energy. If the teacher is system A and the bag (or the bow) with the Earth are the system B, then the discussion may concentrate on energy transfer. From a semiotic point of view, the absence of no contact state between the two systems may create ambiguities integrating transformation with transfer of energy. During the lesson the teacher produced in an initial step also the no contact condition but for the purpose of this study in Figure 12 we present only the contact condition. The same ambiguities can appear in the textbook (Figure 13).

FIGURE 12

Teacher *is taking* a **bag** *(ergotic gesture)*   Teacher *is stretching* a **bow** *(iconic gesture)*

Physical contact between the two systems

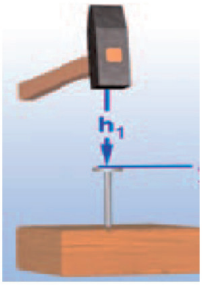
FIGURE 13

Textbook inscriptions of a horse pulling a carriage (image on the left side) and a bulb (image on the right side)

In the image on the left side of Figure 13 mechanical work cannot be identified as a mechanism of energy transfer from a system A (horse) to a system B (carriage) since there is not an initial state which separates and defines these as independent systems. Earth here may not be included in our notion about systems because the motion is horizontal and there are no changes in gravitational potential energy. Actually, the image could imply recognition of a whole system which energy transformations occur within the system. In the image, the vectors of force and displacement may create misconceptions. While the image does not visually distinguish the horse and the carriage as objects assigned to two systems, at the same time the vectors signify the concept of mechanical work (W_F), i.e. that there is a system that exerts external force on another. In other words, the image may imply the horse/carriage as a system while at the same time indicating a transfer of energy from the horse to the carriage.

Correspondingly, the image on right side of the Figure 13 may convey ambiguity between transfer and transformation of energy. By not defining that the system B, which receives the heat, is the air around the bulb, a conceptual blending between transfer and transformation of energy may arise. Actually, it is not clearly specified which is the system B where heat is directed.

FIGURE 14



[hammer] and **[nail]**

[teacher] and **[book]**

Systems are represented by two objects without contact

To overcome this, it is needed to approach systems as visual objects which in an initial state have not contact to each other (Figure 14). The visual separation of the objects (systems) is the key concept. In Figure 14 the hammer is distinguished from the nail and the teacher from the book and thus a visual form is constructed as a prerequisite for the energy transfer: there are two different systems which are going to interact to a next stage. Here, the object nail/Earth and the object book/Earth can be considered as the components of the second system respectively.

Contact + Change

Having clearly identified the systems involved by the *no contact* condition between the objects, we propose then for energy transfer: (i) *contact* between the objects and (ii) *change in the position* for mechanical work and *change in the temperature* for heat.

Mechanical work: contact + position change

From a semiotic point of view transfer of energy through mechanical work can be defined by a contact + position change pattern. In this sense we need, first the objects representing the systems to get in touch and second, the system which receives the energy to start moving. Transfer of energy mechanism through mechanical work is visualized by means of teacher's semiotic resources and textbook inscriptions.

Teacher's semiotic resources

Illustrating mechanical work through contact + position change pattern, two examples are presented in which teacher uses ergotic (Figure 15) and iconic gestures (Figure 16).

FIGURE 15

1.Teacher takes the book **[CONTACT]** *2.Teacher lifts the book up* **[POSITION CHANGE]**

A contact + position change action of energy transfer through mechanical work

In Figure 15 the objects which previously were separated (i.e. the teacher and the book, Figure 14) are in contact now (*contact*). This physical interaction (i.e. ergotic gesture) results to the change in the position of the book; the book is lifted up (*position change*). Teacher applied an external force to the book and through its mechanical work transferred to it energy. In another example, the teacher produces by means of his body an iconic action representing the movement of a swing (Figure 16).

FIGURE 16

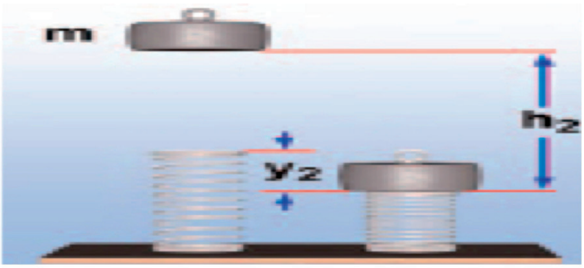
A bodily image of a swing's movement with the three conditions: no contact, contact, position change

For the energy transfer through mechanical work, the teacher at the beginning defines by his speech an imaginative swing and thus specifying *no physical contact* between 'him' and the 'swing'. Then, it is the verbal discourse plus the iconic gesture of 'pushing' that makes the *contact* between the teacher and the 'swing'. Finally, in the third photo, the teacher and the 'swing' are moving together for a time period and thus performing the *change in the position*. By the time the teacher and the swing are moving together, energy transfers occur through mechanical work from one system to another.

Textbook inscriptions

Amongst the 36 diagrams of the textbook we identified only 3 which represent the mechanical work based on the 'no contact', 'contact' and 'position change' pattern.

FIGURE 17



Mass and spring ***[NO CONTACT]***

Mass is putting on the spring ***[CONTACT]***
Spring is compressed ***[POSITION CHANGE: y_2]***

A mass-spring oscillator with carrying the no contact, contact + position change pattern

In the left area of Figure 17, the no contact between the body and the spring separates the objects/systems. The right area conveys two pieces of information: first, the two systems (i.e. body and spring/Earth) come to physical contact and second, the body is putting on the spring which is compressed (position change). The last, namely the spring's change in the position is indicated by the y_2 element. It should be mentioned that the concentration on the 'story' of these three elements (i.e. body, spring, y_2) is crucial for the viewer to construct a visual path of making sense. This path enables the separation/definition of the systems, the physical interaction among the systems and the movement of the system which received the energy.

Heat: contact + temperature change

Correspondingly the contact plus temperature change conditions between two systems are also identified both in teacher's actions and the inscriptions of the textbook.

Teacher's semiotic resources

Concerning teacher's actions, the teacher in one case makes a successful effort to represent without ambiguity the transfer of energy through heat.

FIGURE 18

A bodily representation of energy transfer through heat

In Figure 18 the teacher defines the contact condition by standing in front of the students and thus separating the system A (i.e. himself) from the system B (i.e. the student). Then, he starts rubbing his hands increasing their temperature (system A). Finally, by touching the student's hand, transfer of energy is achieved. This is demonstrated both by student's feeling that he/she holds a warmer hand and by the teacher's verbal discourse 'Is this hot?'. Indeed, by asking the student whether the hand is hot, he implies two things: (a) the temperature of student' s hand is lower than his hand and (b) the student starts feeling that his/her temperature increases. In terms of real world, it is the feeling of teacher's warmer hand that may help student conceptualize that 'something' is transferred from one system to the other due to a difference in temperature.

Textbook inscriptions

In the textbook, it is only one diagram out of 36 inscriptions which contains all the conditions of the 'no contact – contact – temperature change' pattern. The diagram in Figure 19 represents a factory which exploits earth's geothermal energy.

It contains all the needed information without carrying any ambiguities that heat is a mechanism of energy transfer. More specifically, there are two distinct areas, this of a circuit of water in the factory installations settled in the earth's surface and that of another independent circuit of water in earth's underground illustrated in Figure 19 by red - blue color. One can see the *two systems* defined by the two different water circuits. The water circuit in earth's surface is the system A and the water circuit in earth's underground is the system B. These two systems come *in contact* in the kind of building in Figure19 indicated by the dotted line. This building suggests that the two independent water circuits come in touch inside it. As a result, the temperatures of the two systems change. The temperature of the water circuit in earth's surface increases and that is why the arrows representing the water circuit after going into the building turn from blue to red color. Correspondingly, the temperature of the water circuit in the earth's underground decreases and for that reason the arrows turn from red to blue. Actually, after the contact of the two circuits in the building, the warmer water from the earth's underground (system B) becomes colder and the water circuit in earth's surface (system A) becomes warmer.

FIGURE 19

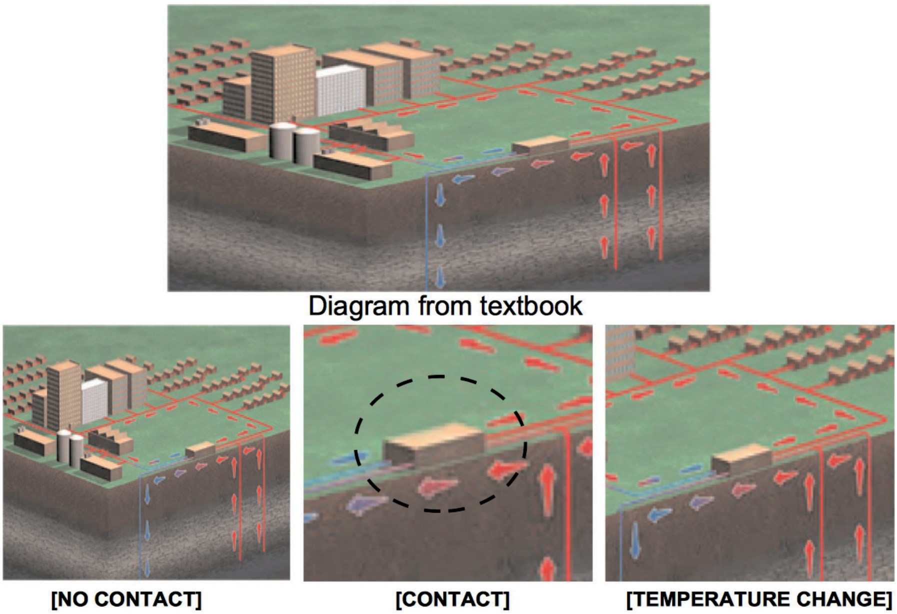
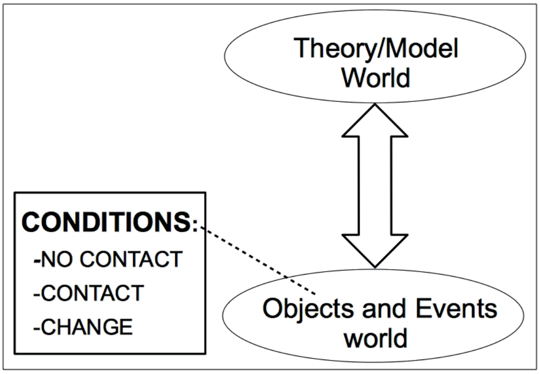


Diagram from textbook illustrating the conditions no contact, contact, temperature change

Discussion

A semiotic model of representing the mechanism of energy transfer was presented in this paper. Following the ideas of a) congruence between the world of objects and events and the physics model and b) avoiding any ambiguities between transfer and transformation of energy, an effort was made to illustrate energy transfer through mechanical work and heat. This was investigated in teacher's actions and in inscriptions of a typical physics textbook. Previous researches have mentioned that without defining and separating the systems in the world of objects and events conceptual blending between transformation and transfer of energy is emerged (Pantidos & Givry, 2016). Extending that, the results of this paper showed that the semiotic schema of *no contact-contact-change* may, with some limitations, transfer aspects of the physics model about mechanical work and heat to the world of objects and events avoiding any ambiguities (Figures 20 and 21).

FIGURE 20



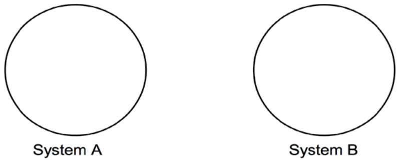
The three conditions for the congruence of the world of model to the world of objects and events

It should be noted that for heat the discussion limits to thermal conduction without including thermal convection and thermal radiation. In the world of material representations mechanical work, as energy flow, is signified with whatever illustrates *postition change*, while heat with anything signifies *temperature change*. In that sense transfer through heat is illustrated by *feeling* and colored *graphic representations* with blue and red color. Especially for the inscriptions, the different colors can sufficiently represent the change in the temperature (Figure 22).

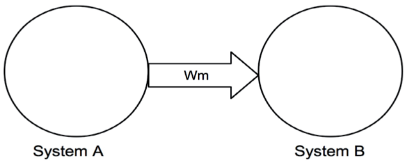
Change in the position, which refers to mechanical work, can be represented realistically; an object is moving from one position to another. On the contrary, change in the temperature can receive both realistic and symbolic representations. In realistic context, thermometers can record the changes (interaction) in the temperature between two bodies. Another realistic representation is what has been described in Figure 18 when the teacher and the student realize the change in the temperature through the haptic feeling. From a symbolic perspective, change in the temperature can be visualized through color differentiation with blue for the low and red for the high temperature, although this is an issue of convention since the blue color is not occurred as low temperature indicator in the physical reality, as well as the red color - though more close to the reality - but still connected with the color of filament.

FIGURE 21

Physics model	Objects and events



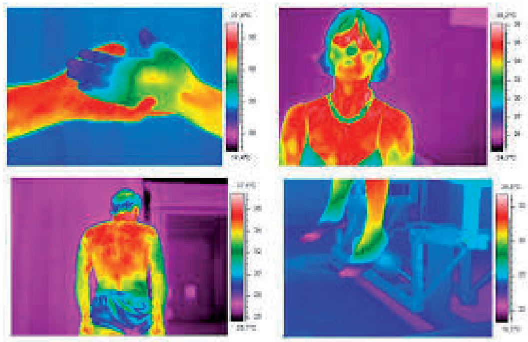
NO CONTACT between objects



CONTACT between objects
+
Change (position or temperature)

Schematic representation of no contact, contact + change conditions

FIGURE 22



Different colors indicate different temperatures suggesting heat as energy flow

Separation and thus specification of the systems as independent entities in the material place is a crucial condition introduced by this paper. Teacher's and students' human bodies might be an active means in overcoming ambiguities appear in written text or in the inscriptions contained in the textbooks. Having the potential of moving in the space, in the case of mechanical work human body produces visual figures of the change in the position. In general, teachers' and students' somatic figures can either introduce the no contact, contact + position change schema or serve as interpretive explanatory filters over the inscriptions.

It should be noted that the model presented in Figure 21 is better to be applied in situations of school life in which the object (system) which receives the transferred energy is initially not moving. When human bodily actions take place as in the examples in Figures 15, 16, it is not possible to perform somatic figures in the space representing observable changes in the speed of an object which is already moving. That is why, in the model in Figure 21 was preferred to insert the idea of 'change in the position' rather than 'change in the speed' as a semiotic indicator in the world of objects and events that can illustrate the effect of an external force.

It seems that the model presented in Figures 20 and 21 has some limitations on its application that depend on what are the system(s) each time. For example, concerning the action 'The teacher lifts up a book' (see Figure 15) we can identify three versions of which are the system(s). Each choice gives different perspectives on the discussion about transfer and transformation of energy. Actually, the conservation of energy principle leads to the same results which however convey different qualities. However, the semiotic model seems not to be applicable in all cases, due to the no contact nature of the gravitational force, but also when a single system is chosen.

(a) Defining three systems: the teacher, the book, the Earth (including table)

The book is a system of a single body and thus two external forces are applied to it; from the teacher (F) and from the Earth (weight). As a single body the gravitational potential energy of the book (U_g) cannot be identified. Also, there is no change in the internal energy of the system (E_i). So, the conservation energy principle for the book between the two states (Figure 15) is:

$$\Delta K + \Delta U + \Delta E_i = W_m + W_e + Q + R$$
$$0+0+0 = W_F + W_g + 0 + 0 + 0$$
$$0 = W_F + W_g$$
$$W_F = - W_g$$

Two transfers are made on the book. From the teacher and from the Earth. These transfers are equal in magnitude and that is why the book in the final position is in an equilibrium state. In the world of objects and events it is needed first to represent and separate the three systems with three objects. However, the main problem is the representation of the gravitational as external no contact force which is difficult to be performed in visual terms. In other words, when only the Earth is an independent system the contact condition (i.e., exertion of the external force) of the semiotic model is difficult to be represented in the world of objects and events. Nevertheless, with the proper choose of the systems, gravitational force can be defined as an internal force and thus being excluded from the world of objects and events as performable agent which leads to energy transfers (see the third case).

(b) Defining one system: the teacher/the book/Earth (including table)
All the forces are internal and thus no transfer of energy occurs. Here, for the three bodied system there are two types of potential energy that change; gravitational (U_g) and chemical (U_c) potential energy. Again here there is no change in the internal energy of the system (E_i). Thus, the conservation energy principle for the teacher/book/Earth between the two states (Figure 15) is applied as below:

$$\Delta K + \Delta U + \Delta E_i = Wm + We + Q + R$$
$$0 + U_{g(f)} - U_{g(i)} + \Delta U_c = 0 + 0 + 0 + 0$$
$$mgh + \Delta U_c = 0$$
$$\Delta U_c = -mgh$$
$$\text{which means } \Delta U_c < 0$$
$$U_{c(f)} < U_{c(i)}$$

It is assumed that in this three-bodied system only between book and the Earth change in the gravitational potential energy is taking place. In this perspective we have no transfers but only transformation of energy within the system teacher/book/Earth. This is why the semiotic model proposed in this article cannot be applied in this case. That is, defining one system only the energy transformation can be approached and not the transfer of it. The gravitational potential energy of the isolated system changes because there was an internal re-configuration between the entities of the system. Indeed, one entity (the teacher) changed his chemical potential energy (U_c). The final value of the teacher's chemical potential energy [$U_{c(f)}$] is less than the initial value [$U_{c(i)}$] indicating that the teacher did (consume) something.

(c) Defining two systems: the teacher, the book/Earth (including table)
The book/Earth (including table) is a system and an external force (F) is applied to it from the teacher (the other system). Now the two-bodied system book/Earth has gravitational potential energy and the gravitational force (weight) applied to the book is an internal force and thus its work does not transfer energy. Also there is no change in the internal energy of the system (E_i). Now, the conservation energy principle for the book/Earth between the two states (Figure 15) will be:

$$\Delta K + \Delta U + \Delta E_i = W_m + W_e + Q + R$$
$$0+U_f - U_i + 0 = W_F + 0 + 0 + 0$$
$$mgh - 0 = W_F$$
$$mgh = W_F$$

In this perspective we have one transfer of energy from the teacher to the book/Earth and transformation of energy within the book/Earth. This transfer (W_F) across the boundaries of the system book/Earth caused a transformation of energy (here only ΔU) within the system making it to move up to h; h is the change in the position of the book (height). Maybe this choice of systems could be the most suitable for school students. The choice of the specific systems excludes weight as external force and thus it is not necessary to visualize it during contact condition. In addition, two systems are identified allowing simultaneous discussion of energy transfer and transformation, which is consistent with the physics model about energy as it is presented in Figure 2.

It is on the authors' intention the semiotic model presented in this paper to be explored also in the other two mechanisms of energy transfer; electricity and radiation as well as to test its impact in learning. However, it should be noted that these two concepts are different in nature compared to mechanical work and heat through thermal conduction. Electricity although has correspondences to mechanical work in the sense that both convey the idea of 'moving sth' (i.e., object/electric charge), has also the difficulty in terms of visual semiotics of representing 'contact' since the nature of electrical force is a no contact force. It might be the expressiveness of the human body in representing interactions from a distance which however could denote 'contact'. This would also solve the problem, which was described above, of representing in the world of objects and events the gravitational force as external force. The 'non-tangible', in terms of the visual world, nature of radiation makes also difficult to be represented in the material world. In general, any effort of interconnecting the world of physics model with the world of objects and events should follow the wider context of conservation energy principle supported by many researchers rather than that of, with no holistic value, work-energy theorem (Jewett, 2008).

Acknowledgements

We are grateful to Psychico College Middle School in Greece and the teacher participated in the Examples for crucially contributing to this study. We would also like to thank Evangelos Vitoratos and Dimitris Koliopoulos for their fruitful comments.

References

Antoniou, N., Demetriadis, P., Kampouris, K., Papamichalis, K., & Papatsimpa, L. (2006). *Physics 2nd grade of lower secondary school.* Athens: OEDB (in Greek).

Bächtold, M. (2018). How should energy be defined throughout schooling? *Research in Science Education, 48*(2), 345-367.

Delegkos, N., & Koliopoulos, D. (2020). Constructing the "energy" concept and its social use by students of primary education in Greece. *Research in Science Education, 50*(2), 393-418.

Doménech, J. L., Gil-Pérez, D., Gras-Martí, A., Guisasola, J., Martínez-Torregrosa, J., Salinas, J., & Vilches, A. (2007). Teaching of energy issues: A debate proposal for a global reorientation. *Science & Education, 16*(1), 43-64.

Duit, R. (1987). Should energy be illustrated as something quasi-material? *International Journal of Science Education*, *9*(2), 139-145.

Duval, R. (2006). A cognitive analysis of problems of comprehension in a learning of mathematics. *Educational Studies in Mathematics, 61*(1), 103-131.

Eisenkraft, A., Nordine, J., Chen, R. F., Fortus, D., Krajcik, J., Neumann, K., & Scheff, A. (2014). Introduction: Why focus on energy instruction? *Teaching and Learning of Energy in K–12 Education* (pp. 1-11). Springer, Cham.

Fragkiadaki, G., Fleer, M., & Ravanis, K. (2019). A cultural-historical study of the development of children's scientific thinking about clouds in everyday life. *Research in Science Education*, *49*(6), 1523-1545.

Givry, D., & Roth, W. M. (2006). Toward a new conception of conceptions: Interplay of talk, gestures, and structures in the setting. *Journal of Research in Science Teaching, 43*(10), 1086-1109.

Givry, D., & Pantidos, P. (2012). Toward a multimodal approach of Science teaching. *Skholê, 17*, 123-130.

Givry, D., & Andreucci, C. (2015). Un schéma vaut-il mieux qu'un long discours ? Effets de l'utilisation de deux types de registres sémiotiques sur la mobilisation des idées des élèves de Seconde lors d'une évaluation sur les propriétés des gaz. *Education & Didactique*, *9*(1), 119-142.

Givry, D., & Pantidos, P. (2015). Ambiguities in representing the concept of energy: A semiotic approach. *Review of Science, Mathematics and ICT Education*, *9*(2), 41-64.

Jewett, J. (2008). Energy and the confused student IV: A global approach to energy. *The Physics Teacher, 46*, 210-217.

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *The Journal of Learning Sciences, 4*, 39-103.

Kaliampos, G. (2015). A small scale, qualitative study on exploring alternative conceptions of mechanics in students with autism. *Educational Journal of the University of Patras UNESCO Chair, 2*(2), 110-119.

Koliopoulos, D., & Argyropoulou, M. (2012). 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., & Ravanis, K. (2000). Réflexions méthodologiques sur la formation d'une culture concernant le concept d'énergie à travers l'éducation formelle. *Spirale, 26*, 73-86.

Kress, G., Jewitt, C., Ogborn, J., & Tsatsarelis, C. (2001). *Multimodal teaching and learning: The rhetorics of the science classroom*. London: Continuum International Publishing Group.

Leontiev, A. N. (1978). *Activity, Consciousness, and Personality*. Hillsdale: Prentice-Hall.

Lee, H. S., & Liu, O. L. (2010). Assessing learning progression of energy concepts across middle school grades: The knowledge integration perspective. *Science Education, 94*(4), 665-688.

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

Lemke, J. L. (1998). Multiplying meaning: Visual and verbal semiotics in scientific text. In J. R. Martin & R. Veel (Eds.), *Reading Science* (pp. 87-113). London: Routledge.

Lewis, E. L., & Linn, M. C. (1994). Heat energy and temperature concepts of adolescents, adults, and experts: Implications for curricular improvements. *Journal of Research in Science Teaching, 31*(6), 657-677.

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. H. (2005). Teaching about energy. Available at: http://eprints.whiterose.ac.uk/129328/1/2005_Millar_Teaching_about_energy.pdf.

Pantidos, P. (2019). Epistemic, cognitive and semiotic significations in science teaching: The case of sound. *European Journal of Education Studies, 6*(4), 210-231.

Pantidos, P., & Givry, D. (2016). Connecting the teaching of mechanical work with the model of energy: a semiotic approach. *Educational Journal of the University of Patras UNESCO Chair, 3*(2), 317-326.

Pantidos, P., Valakas, K., Vitoratos, E., & Ravanis, K. (2008). Towards applied semiotics: An analysis of iconic gestural signs regarding physics teaching in the light of theatre semiotics. *Semiotica, 172*(1), 201–231.

Pozzer-Ardenghi, L. (2009). Research on inscriptions: Visual literacy, authentic science practices, and multimodality. In K. Tobin & W.-M. Roth (Eds.), *The world of science education. Handbook of research in North America* (pp. 307-324). Rotterdam: Sense Publishers.

Pozzer-Ardenghi, L., & Roth, W.-M. (2010). Toward a social practice perspective on the work of reading inscriptions in Science texts. *Reading Psychology, 31*(3), 228-253.

Scherr, R. E., Close, H. G., Close, E. W., & Vokos, S. (2012). Representing energy. II. Energy tracking representations. *Physical Review Special Topics-Physics Education Research, 8*(2), 1-11.

Tang, K. S., Tan, S. C., & Yeo, J. (2011). Students' multimodal construction of the work-energy concept. *International Journal of Science Education, 33*(13), 1775-1804.

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

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, UK: Open University Press.

Tiberghien, A., Vince, J., & Gaidioz, P. (2009). Design-based research: Case of a teaching sequence on mechanics. *International Journal of Science Education*, *31*(17), 2275-2314.

Vince, J., & Tiberghien, A. (2012). Enseigner l'énergie en physique à partir de la question sociale du défi énergétique. *Review of Science, Mathematics and ICT Education, 6*(1), 89-124.

Warren, J. W. (1982). The nature of energy. *European Journal of Science Education, 4*(3), 295-297.

Watts, D. M. (1983). Some alternative views of energy. *Physics Education, 18*(5), 213-217.