Design, development and validation of a teaching proposal for energy: results from a pilot implementation

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Abstract

Learning about energy is recognized as an important objective of science teaching starting from the elementary school. This creates the need for teaching simplifications that compromise the abstract nature of this construct and students' need for a satisfactory qualitative definition. Traditional teaching approaches have failed to respond to this need in a productive manner. In an attempt to maintain consistency with how energy is understood in physics they tend to either provide abstract definitions or bypass the question "what is energy?", which is vitally important to students. We suggest that shifting the discussion to an epistemological context presents a means to overcome the difficulties inherent in introducing energy as a physical quantity. We propose a teaching approach, for students in the age range 11-15, which introduces energy as an entity *invented* in the context of a *theoretical framework* for explaining changes encountered in physical systems. This framework is elaborated in a progressive manner through the assignment of various properties to energy (i.e. transfer, transformation, conservation and degradation). Each property is introduced in a manner that highlights its contribution to the explanatory power of the theoretical framework. The paper outlines the rationale underlying this teaching approach and describes the activity sequence. It also reports findings from a pilot implementation with a group of students, which are encouraging with respect to the position taken in this approach. The paper concludes with a discussion of the implications for validating activity sequences and for teaching and learning about energy.

Introduction

Learning about energy is recognized as an important objective of science teaching starting from the elementary school (AAAS, 1993). This creates the need, which is more salient in the case of the upper elementary and lower secondary grades, for teaching simplifications that compromise the abstract nature of the concept and students' need for a satisfactory qualitative definition. Despite the fact that the topic of *energy* has received much attention in the science education research literature (Schmid, 1982; Warren, 1983, 1986; Duit, 1984, 1987; Solomon, 1992; Kesidou & Duit, 1993) it is the case that traditional teaching approaches have failed to respond to this need in a productive manner. In an attempt to maintain consistency with how energy is understood in physics they tend to either provide abstract definitions or bypass the question "what is energy?", which is vitally important to students. The dominant approach in traditional science teaching is to introduce energy as the ability to do work (Driver & Millar, 1986). This approach usually begins with the definitions of force and work and tries to link work with energy as an abstract concept. The law of conservation of energy is introduced as a fundamental aspect of nature and much emphasis is placed on quantitative applications of this law in analyzing what are called energy problems. We believe that the early introduction of the conservation law and its widespread application for solving quantitative exercises, (a) blurs the definition for students and, (b) instead of highlighting its epistemological aspects tends to reduce energy into a meaningless book-keeping algorithm constrained to the use of solving 'energy problems'.

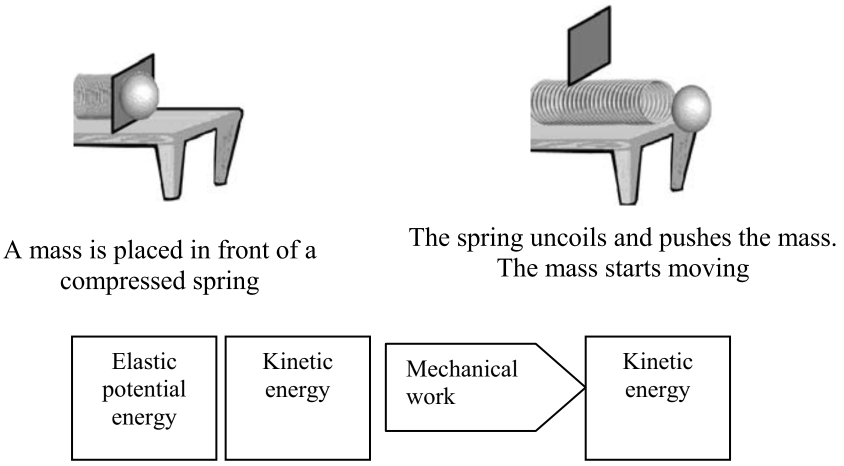
We take the perspective that the question '<u>what is energy?'</u> is of fundamental importance to students and to a large extent determines their ability to integrate this construct effectively in their learning pathway. This study reports on an attempt to develop learning materials on the topic of energy for students in the age range 11-15 years old. Our research rests on the premise that students need to acquire a qualitative, albeit scientifically valid, notion of the concept of *energy*, which can be elaborated progressively so as to become more quantitative and increasingly aligned with scientifically accepted ideas. In view of the various difficulties that are inherent in introducing energy as a physical quantity we suggest that the discussion could be usefully shifted to an epistemological context.

The proposed teaching approach seeks to introduce energy as an *invented* entity in the context of a *theoretical framework* for explaining changes encountered in physical systems. The sequence of learning activities is organized in three sections. The first includes two case studies from the history of science; Aristotle's notion of violent and natural motion and Lavoisier's caloric theory. These are accompanied by activities targeted at helping students to (i) differentiate between observations, theories and models, (ii) appreciate the role of each in science and (iii) recognize how they are connected. The emphasis is placed on guiding students to appreciate the idea that in science we often build models and invent theoretical ideas in order to describe, interpret and predict phenomena. The second section promotes two main objectives. The first includes helping students appreciate the value of a single framework that could be used to explain the functioning of very different systems. The second relates to the introduction of energy as a construct that could serve such a unifying role. The discussion related to the latter objective is embedded in the epistemological context that has been formulated in the first section. In particular, energy is introduced as a hypothetical construct in the context of a theoretical framework, which has been invented in science because of its facility to provide a common account for the various changes that are observed in systems, regardless of the domain they are drawn from.

The remaining part of the activity sequence elaborates the theoretical framework of energy in a gradual manner. In particular, students are guided to progressively develop the various properties of energy, namely transfer, form conversion, conservation and degradation and to appreciate how each contributes to the interpretive, descriptive and predictive power of the theoretical framework. For instance, they are guided to appreciate (i) energy transfer and form conversion as a class of mechanisms, which can be used to account for changes occurring in physical systems, (ii) energy conservation as a constraining condition that prohibits certain changes, and (iii) energy degradation as a property of energy, which allows predicting the evolution of processes in time. Students are also guided to develop the energy chain as a model that could be used to graphically describe the energy transfers and form conversions that relate to a given system that is under consideration. Figure 1 provides an example of an energy chain, and also a verbal description, that relates to the system of a mass and a spring. Students are guided to use this model as a means to apply the theoretical framework of energy to a physical system of interest and derive a qualitative analysis, in terms of energy transfers and form conversions, that relates to the operation of that specific system.

Methods and Sample

The sequence of the learning activities has been implemented in the context of a computer/science club. Participants were 28 students in the age range 11-14 years old who volunteered to take part. Students met with the instructors twice a week for 1,5 hours over a period of six weeks. During the teaching intervention we assessed students through two open-ended tests, which were administered before and after the teaching intervention. The first (Figure 2) pertains to students' understanding of the model of energy as a cause for changes in systems drawn from diverse phenomenological domains. In particular, students were presented with physical systems demonstrating a certain change and in each case they were asked to come up with a single explanation that accounts for a couple of changes. The test consists of two parts. The first part was administered before and after the teaching intervention while the second part was only given as a post-test. The second test pertains to students' ability to provide accounts of the energy transfers and transformations in order to analyze systems and describe the changes they undergo. In this test students were presented with two physical systems and in each case they were asked to describe the "trace" of energy. The first system included a worker using an electric drill to perforate a wall and the second showed a woman striking a ball with a golf stick.



The elastic potential energy that is initially stored in the spring is converted into kinetic energy. As it uncoils, the spring pushes on the mass and it transfers energy trough mechanical work, which is then stored in the form of kinetic energy of the mass.

Figure 1. An example of energy chain

Results

Data were exposed to phenomenographic analysis (Marton & Booth, 1997) in order to discern categories of responses. The categories relevant to the first task are illustrated in Table 1 while Table 2 shows the percentages and frequencies of students' responses across these categories in the pre- and post-tests.

Can you think of a single explanation that can account for the rotation of the blades in both cases? Explain your reasoning.	*Can you think of a single explanation that can account for the spin of the drill in both cases? Explain your reasoning*

Figure 2. Task for the model of energy as a cause of changes

As shown in Table 2, the number of responses that relied on energy transfer and transformation as a common explanation for the changes was significantly higher in the post-tests and this is encouraging as an indication of students' ability to analyze changes in terms of energy. Students' responses to the second test were evaluated with respect to their accuracy and comprehensiveness. Prior to the intervention, none of the students was able to effectively analyze the systems in terms of energy transfers and transformations. Most of the students (approximately 85%) constrained themselves to only citing the objects they considered relevant to the energy chain in both systems. For example, a common response in the case of the electric drill system is that "*energy goes from the plug to* *the drill"*. Other students provided irrelevant responses such as *"the drill will perforate a hole on the wall"* and only a small number of students referred to energy transfer (e.g. student 4 in Table 3). Also, most of the students stated that energy will disappear or will be used up during the processes taking place in the systems. After the teaching intervention, most students were able to provide accounts for energy transfer and transformation in both systems. In addition to this, most students recognized that energy will not disappear when the process will be over and that it will be stored in the surrounding air in the form of internal energy. Table 3 compares typical pre- and post-test responses from four students.

Description of Response	**Typical student response**
Energy transfer & transformation	In both cases energy that is stored in the system is transferred to the blades and this makes them spin.
Energy (vagueness)	The blades of the windmill spin because of wind energy and the blades of the electric motor because of the energy in the battery.
No common explanation	The blades of the windmill spin because of the wind and the blades of the electric motor spin because of its connection to the battery.
Force	In both cases the blades rotate because of force; the force of wind and the force of battery.
Irrelevant responses	The blades spin because something makes them do so.

Table 1. Categories of Responses

Despite the noteworthy improvement in students' ability to analyze systems based on the mechanisms of energy transfer and transformation, there are two issues that warrant further attention. First, even though some of the students could undertake a detailed and systematic analysis of the systems in terms of the mechanisms of energy transfer and transformation (e.g. student 4 in table 3) most of them tended to constrain themselves to only describing a small portion of the energy chains (e.g. student 2). Second, students' responses varied with respect to their accuracy and many students tended to yield to fallacious ideas. Their fragile understanding of energy degradation and energy as stored in systems rather than in isolated objects (e.g. in the oxygen-fuel system)

	Part A *Pre-test*		*Part A* *Post-test*		*Part B* *Post-test*	
	N	*%*	*N*	*%*	*N*	*%*
Energy transfer & transformation	*2*	*9*	*15*	*58*	*18*	*69*
Energy (vagueness)	*6*	*27*	*2*	*7.5*	*1*	*4*
No common explanation	*10*	*46*	*5*	*19*	*3*	*11.5*
Force	*4*	*18*	*1*	*4*	*3*	*11.5*
Irrelevant responses	*-*	*-*	*2*	*7.5*	*1*	*4*
Omitted Response	*-*	*-*	*1*	*4*	*-*	*-*
Total	*22*	*100*	*26*	*100*	*26*	*100*

Table 2. Categorization of students' responses in the pre- and post-tests

and also their tendency to identify mechanical work with force present conceptual difficulties that were prevalent in their responses.

Implications & Conclusions

Our data suggest that the curriculum materials designed in the context of the project EKTEMA can help students develop the model of energy as a cause of changes and make appropriate use of the mechanisms of energy transfer and transformation in analyzing systems. However, despite the promising results from data analysis, there is an important issue to address, which is currently under consideration, in the possible revisions in the sequence of the learning activities that could further enhance students' conceptual understanding and help them overcome persisting conceptual difficulties.

1 **Pre-test response:** *Energy is transmitted from the wire to the drill. When the process is over, energy will be spread to the air.*

Post-test response: *The energy chain begins with chemical energy from the plug. Energy is transformed to electrical energy in the wires and to kinetic energy at the drill. Sound and heat will be transferred to the environment and they will end up as internal energy. When the process is over, energy will be transferred to the environment (internal energy) through heat and sound.*

2 **Pre-test response:** *Energy goes from the plug to the drill. The energy makes the blades rotate and perforate a hole on the wall. When the process is over, energy will disappear.*

Post-test response: *Energy is transferred to the drill through the wires. The drill then starts to function and it perforates a hole on the wall. When the process is over, energy will be transferred to other parts of the system increasing the energy already stored in them. Energy will not disappear.*

3 **Pre-test response:** *Energy will be transferred from the man to the drill. This causes the drill to rotate and to perforate a hole on the wall. Energy is used up during the process.*

Post-test response: *Electrical energy is transferred through the wires to the drill, which starts functioning and perforates a hole on the wall. When the drill is rotating there is also sound and heat. When the process is over energy is not lost. It is stored in the environment in the form of internal energy.*

4 **Pre-test response:** *At the beginning, energy was stored in the stick. The energy was then transferred to the ball which started to move.*

Post-test response: *Energy is initially stored in the woman and the oxygen in the form of chemical energy. When the woman strikes the ball, energy is transferred to the ball through mechanical work. A part of the energy that is transferred to the ball is converted into kinetic energy and the remaining part into heat and sound and it is transferred to the air.*

Table 3. Categorization of the students' responses in the pre- and post-tests

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