A vertical pathway for teaching and learning the concept of energy

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Abstract

A vertically integrated, research-based approach to teaching the concept of energy in primary, middle and upper secondary schools was designed. In primary school, the energy concept is developed from the idea of a state property of bodies, occurring in four types, which transform from one to another during interactions. In middle school, transformations are analyzed in terms of variations in quantities associated with each energy type in simple experiments. In upper secondary school, the conservation of energy is addressed through the conversion of the different types into internal energy to identify their formal definitions. The learning process is monitored by means of students' responses to tutorials and pre/post-tests, and interviews.

Keywords

Energy, transformation, vertical path, primary, middle school

Résumé

Une approche éducativesur l'énergie, basée sur la recherche et verticalement intégrée, a été connçu pour l'école primaire, secondaire moyenne et secondaire supérieure. À l'école primaire le concept d'énergie est développé á partir de l'idée *d'une propriété d'état des corps de quatre types, se transformant l'un á l'autre pendant les interactions entre différents systèmes. Dans l'école moyenne les transformations sont analysées en termes de variation des quantités associées á chaque type d'énergie dans le cadre de la réalisation de simples expériences. Dans le secondaire supérieur, la conservation de l'énergie est adressée á travers de la conversion de différents types d'énergie en énergie interne pour identifier leur définition formelle. Le processus d'apprentissage est contrôlé au moyen de tutoriaux, comparaison de pré/post-tests et entretiens.*

Mots-Clés

Énergie, transformation, trajectoire verticale, école primaire, collége

Research on students' pre-instruction ideas and conceptions of the concept of energy show that many pupils: associate energy with specific systems (living creatures, batteries, sources) or processes (human activities, explosions, combustion) (Watts, 1983; Driver & Warrington, 1985; Solomon, 1992; Ross,1993; Trumper, 1993; Duit & Haeussler, 1994; Goldring & Osborne, 1994); consider energy as a substance that moves from one system to another (Watts, 1983; Solomon, 1983; Taber, 1989; Nicholls & Ogborn, 1993; Dawson & Stein, 2008); have difficulties recognizing potential and internal energy and in general do not associate energy with a static system (Driver & Warrington, 1985; Lawson &McDermott, 1987; Brook & Wells, 1988; Carr & Kirkwood, 1988). Moreover, students have difficulty distinguishing energy from other physical quantities such as force or power (Watts, 1983; Lawson & McDermott, 1987; Solomon, 1992; Trumper, 1993; Duit & Haeussler, 1994; Goldring & Osborne, 1994; Hirŋa, Halik & Akdeniz, 2008; Mann &Treagust, 2010) and fail to reach a scientific point of view of energy and of everyday expressions such as energy dissipation, energy waste, and energy storage (Duit & Haeussler, 1994; Leggett 2003; Melzer 2004; Hirça, Çalik & Akdeniz, 2008).

In part because of these findings, much attention in science education has been devoted to the teaching and learning of the concept of energy, in particular in inquiry-based educational strategies beginning in primary school. Some research approaches have documented the importance of addressing the concept of energy early, using hands-on experiences as the basis for recognizing energy transformations (Brook & Wells, 1988; Carr & Kirkwood, 1988; Papadouris, Constantinou & Kyratsi, 2008; Golberg, Otero & Robinson, 2010). In spite of these efforts, no consensus has been reached on the sequence to follow, in particular on the issues of whether and how to: define energy, introduce energy forms, and treat conservation of energy at different school levels (Dahncke, Duit & Niedderer, 1973; Warren, 1982; Falk, Herrmann & Schmid, 1983; Duit, 1987; Lawson & McDermott, 1987; Trumper, 1990; Chisholm, 1992; Goldring & Osborne, 1994; Driver & Warrington, 1995; Boohan & Ogborn, 1996; Kaper & Goedhart, 2002; Ogborn & Whitehouse, 2000; Millar, 2000, 2005; Hobson, 2004; Papadouris, Constantinou & Kyratsi, 2008; Jewett, 2008). In primary schools in particular, the more popular approaches focus on forms of energy (EIA, 2009) as intermediate language useful for treating the concept of energy qualitatively (Goldring & Osborne, 1994; Ruset & Mogos, 2001; Kaper & Goedhart, 2002; Hobson, 2004; Koliopoulos et al., 2009). Forms of energy are introduced also in approaches focusing on an operational approach to energy using toys and everyday situations (Tsagliotis, 2001). Different authors criticize aspects of the energy forms approach, both from the view point of physics and in view of its merits in a teaching/learning strategy. In particular they note that energy forms such as chemical, nuclear, wind energy are not identified as physical quantities, but rather as sources or means of production of electrical energy (Sefton, 2004; Millar, 2005) and that the different forms, in fact, do not have a precise definition in physics, and in particular do not have a thermodynamic definition (Millar, 2005; Jewett, 2008). Thus they argue that this approach risks encouraging students to learn the different forms as words or labels and not as physical quantities, and consequently not as different manifestation of the same physical quantity, which is simply energy (Duit, 1984; Ellse, 1988; Millar, 2005).

An educational approach was designed in which the concept of energy is developed in a coherent vertical path, (Heron, Michelini & Stefanel, 2008, 2009). The path introduces only the following forms of energy, which we named "types" of energy: kinetic energy, potential energy, internal energy and energy associated with light. At the primary school level, our angle of attack is through the (internal) energy of the human body, which constitutes a very natural approach for pupils, as demonstrated in the literature (Watts, 1983; Solomon, 1992; Trumper, 1993; Duit & Haeussler, 1994; Goldring & Osborne, 1994; Driver & Warrington, 1995; Mann & Treagust, 2010) and in our preliminary explorations (Michelini & Stefanel, 2011). The focus is on the abstract nature of energy as a state quantity of a system. Pupils recognize the different types of energy and energy transformations associated with bodies' interactions (Heron et al., 2008). In middle school, the goals mentioned previously are reached through the analysis of systems such as a bouncing ball, a mass connected to a spring, and Newton's cradle, all of which offer students the opportunity to carry out simple measurements and consider preliminary energy balances (Heron et al., 2009). In Upper Secondary School, we exploit the fact that all energy forms can be converted into internal energy, rather than introduce energy through the work-energy theorem. Students use sensors and computers to analyze processes, construct energy balances, and develop more formally the different types of energy (Colombo, Michelini & Stefanel, 2008).

All three integrated paths are based on an inquiry strategy, implemented with *tutorials* for students. The first two paths have been tested in pilot classes, and some preliminary tests have been made with the path intended for upper secondary school. In addition, within the framework of Shulman's Pedagogical Content Knowledge (Shulman, 1987), research was conducted with prospective primary school teachers attending a formative module based on the path for primary schools.

From our perspective the major challenge lies in devising a treatment of energy that is by necessity largely qualitative for the youngest pupils, but that does not betray the essentially quantitative nature of the concept. Our response has been to undertake a long-term project aimed at the development of a vertically integrated curriculum in which ideas that are introduced in primary school are refined and extended in middle and high school and that incorporates, in a coherent way, the preparation of prospective primary school teachers. The basic idea for curricular development is the gradual growth of subject related energy concept, building step by step its fundamental elements, in simple, common situations. Obviously it is possible (and often desirable) to introduce simple models that may be found later to be inadequate in the face of additional evidence or expanded circumstances. This is not what we mean to avoid. We mean to avoid the promotion of ideas, such as the notion of energy as a quasi-material substance, that will be found to be in direct conflict with scientifically accepted ideas.

In the following section we discuss the choices made in the construction of the paths for different levels of school. Then we present the educational paths for the primary and middle level, discuss the testing that was carried out in pilot classes and the methodology used to collect and analyze data. Finally the results for each path, the overall results, the conclusion and implications are presented.

Defining the goals of instruction for the primary and Middle school paths

In this section we mention a few studies whose methods and findings influenced the curricular proposal that is the subject of this paper. We start with our major goals and then briefly discuss some of the ideas we chose not to emphasize.

Major goals

- *Energy exists in different types, synthesizable in the following four: kinetic energy (energy associated to rotational and translational movements), gravitational and elastic potential energy (referred to in the curriculum as "falling" and "spring" energy), internal energy (associated with internal structure and temperature) and energy associated with light.*

The sequence, illustrated in the next paragraph for primary students, begins with the idea that the "human energy" (recognized as internal energy of the human body) needed to move increases as a result of eating food. This starting point, consistent with Millar (2005), was chosen because of the well-known tendency of young students to associate energy with living beings and with motion (Watts, 1983; Solomon, 1992; Trumper, 1993; Duit & Haeussler, 1994; Goldring & Osborne, 1994; Driver & Warrington, 1995) and could thus be the basis from which we could gradually "grow" a larger set of phenomena associated with energy through a succession of small steps.

- *Energy is an abstract property of a system in a particular condition (a state property, described in everyday terms); not a material substance.*

The well-known tendency for pupils to conceptualize energy as a quasi-material substance that can flow from one object to another (Solomon, 1983; Watts, 1983; Taber, 1989; Nicholls & Ogborn, 1993; Dawson & Stein, 2008) may be natural, and may encourage the development of the ideas of transfer and conservation, but it is an idea that is not consistent with the contemporary view of energy held by physicists (Arons, 1999; Sefton, 2004; Millar, 2005). Therefore, in anticipation that the instructional path we are developing should articulate with instruction in middle and high school, we decided to stress energy as a property of a system in a particular condition (for example, the position of an object in relationship to others).

- *Transformations of energy occurs both in everyday interactions and in some other significant processes related to large-scale energy production.*

Some researchers (Brook & Wells, 1988; Carr & Kirkwood, 1998) point out that questions about energy that concern static situations often cause confusion among students, and moreover, are often unanswerable. We follow the recommendation that energy concepts need to be invoked in situations in which observable *changes* are taking place: wheels spinning more quickly, objects falling from higher to lower positions, temperatures increasing, etc. We also follow the recommendation of Carr and Kirkwood (1988) that the initial and final states of the systems must be clearly identified to focus students' attention on the energy types involved in the physical situation being analyzed.

Brook and Wells (1988) makes a related point in observing that students often associate energy only with effects they can perceive. Therefore we chose some cases in which the transformation of energy is partially identified at a macroscopic level (e.g., when salt is dissolved in water, we can observe the change in temperature of the water) and explicitly address the accompanying change that we assume must be occurring at a different level (the chemical processes that are invisible when the salt dissolves). The purpose of these experiments is to introduce other types of energy, and also to reinforce the idea of transformation as a process in which energy is neither created nor lost.

- *Energy is a physical quantity that is a measurable property of a system*

The usefulness (and in some sense the meaning) of energy is tightly linked to our ability to measure it and thus keep track of it as it undergoes transfer and transformation. We did not want to stress quantitative experiments for this age group, but we did introduce the idea of measurement in the sections dealing with energy available from food and gravitational potential energy. Students should know how some types of energy or better changes in energy can be observed and measured. This aspect is emphasized to a greater extent when considering the approach with middle school students.

What is not emphasized in the paths for primary and middle school

- *The concept of work*

We judged that the concept of work was probably beyond the grasp of primary and middle students due its relation with the concept of force, and considerable effort must be made to differentiate the scientific concept of work from the everyday sense of the word. At the secondary school level, work and the work-energy theorem are introduced.

- *The principle of energy conservation*

Conservation in the quantitative sense, famously summarized by Feynman (1963), is a part of our approach to energy in high school, but we judged it to be beyond the grasp of students in primary and middle school. For these ages, nonetheless, we wanted the idea to be a natural extension when encountered in later studies. Therefore the constancy of energy is hinted at in a section in which students observe an object hanging from a spring and bobbing up and down. Moreover, in some sense the idea of conservation underlies the rationale of the entire path in the following sense: each time an effect is seen that has previously been identified as resulting from an energy transformation (e.g., a wheel is set in motion) there is a commitment to the idea of transformation and therefore a new form of energy must be recognized by the variation of a quantity as an effect associated with the new energetic state of the system.

- *Forms of energy associated with sources*

The forms of energy related to the different ways in which electric current is produced are not introduced in the first phase. We propose to distinguish between types of energy, according to the physics point of view (kinetic, potential, internal energy and energy associated to light) and forms of energy associated with sources (transformation sites), such as solar, nuclear, and wind energy, which indicate in the everyday language both the energy associate with the sun, nuclei, and wind, as well as the transformation of energy associated with these kinds of sources.

The Path in Primary School

In this section we outline the 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.

The sequence contains many activities that allow students to experiment. Most of the apparatus consisted of toys. Therefore the materials are inexpensive and easy to find, as well as being familiar and engaging to students.

The first activity took advantage of pupils' natural interest in their own bodies by introducing "human energy" as something that can be obtained from the food we eat. The topic was considered a good starting point because of research results that suggest that young pupils tend to think of energy as something possessed by animate objects, such as people and animals. Students studied nutrition labels on food and discussed the meaning of the energy values shown there. They asked how the numbers are obtained and were told that it is by burning the food and measuring the effect on the temperature of some water. They conduct such experiments with peanuts. They were told about how people can eat the same amounts of food but have different body shapes because of differences in metabolism. The methods used by nurses in hospitals to assess the metabolism of individuals were described.

The energy available from food led to the question: what can we do with the energy we have in our bodies? Riding bicycles was an example that was used to introduce the next topic – rotational kinetic energy produced by turning the wheel of a bicycle (both on an upturned bicycle and toy bicycles). The transformation was described as the partial conversion of their own energy to the energy of the wheel. They connected a dynamo-powered lamp to the bicycle and noticed that it takes more human energy to make the wheel turn at the same rate while also making the lamp work. As part of their homework they were asked to name four other objects that rotate and to identify what sort of energy was transformed into rotational energy. This exercise set the stage for the next section.

The students then looked at pictures of windmills and turbines set in motion by flowing water. They were expected to make the connection that non-animate objects, water and air, could have the same effect as an animate object (a person) and therefore could reasonably be said to have energy as well.

The next step in the progression introduced a new type of energy. A toy turbine was used to show that falling bodies can also cause a wheel to turn (Figure 1). First, sand was slowly poured onto the blades of the turbine, to mimic the flow of water. Then a stream of beads and finally a single ball was dropped. The students found that balls dropped from different heights had different effects.

Figure 1

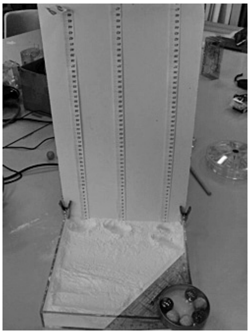
A toy used to demonstrate that falling objects can cause a wheel to turn

The type of energy that was transformed into the rotational kinetic energy of the wheel is referred to as "falling" energy, with the meaning of a state property associated with the falling of the body from that position. Students followed an exploration of the behavior of different balls dropped on the floor. They observed that different balls bounce back to different heights. The fact that some balls bounced back up to nearly the same height as that from which they were dropped was used to establish that a portion of their energy is transformed into internal energy of the ball or the floor.

Experiments with a Newton's cradle apparatus followed. The pupils observed that when one ball is pulled back and released, it collides with the other balls and causes the opposite ball in the set to rise to nearly the same height. They also noted that eventually the balls slow down and stop completely. This observation is interpreted as evidence that the initial energy of the original ball has been transformed into some other type, not that it is "lost". Students discuss several possibilities, in particular the clicking sound produced by the colliding balls.

The focus was then turned to the energy associated with falling objects. Experiments were conducted in which identical balls were dropped from different heights into a box of flour. Craters of different depth were produced (Figure 2). The change in the state of the flour was taken as evidence of an interaction – and a transformation of energy. The same phenomenon was observed when balls of different size were dropped from different heights. The students were asked to examine the quantity involved: the height of the ball above the ground or the height of the ball above the container of flour. They readily concluded that it is the height through which the ball falls that affects the depth of the crater created. The students decided that the weight of an object and the height through which it falls determines the amount of its "falling" energy.

FIGURE 2



Balls were dropped into a box filled with flour to explore the variables that affect the depth of the craters formed

The pupils were then shown that instead of merely dropping a ball from a specific height, they could launch it vertically upward using a toy ball launcher (Figure 3a). Inspecting the toy they found that the mechanism included a compressed spring. Students experimented with compressing the spring fully or only partially and noticed that the ball reaches different heights. These observations led to the identification of a new type of energy – the energy associated with the state of a spring. Thus the link was made between "human energy" initially used to place the ball at a specific height, and spring energy, which would accomplish the same task.

FIGURE 3A AND 3B

a) Toy used to launch balls upward; b) Car and track system with elastic launcher

Pupils next investigated an object suspended from a spring. They observed that if the spring is stretched and released the object oscillates up and down. They decided that energy is transformed from "falling" energy to kinetic energy and to elongation or "spring" energy and so forth. Their attention was drawn to the fact that the oscillations repeat the same pattern, with the object returning to the same position. The notion that "something" in this process is not being lost was introduced, but not stressed at this point.

The next section provided students another opportunity to apply and integrate the ideas developed thus far. They experimented with toy cars on plastic tracks that have hills and loops (Figure 3b). They found they can launch a car by pressing it against a spring and then releasing it. They could influence the height to which the car rises by manipulating the way the spring was compressed. They discussed the successive transformations between energy stored in the spring, energy associated with the motion of the car, and the energy associated with its height.

Another new type of energy was introduced in the next section. The students discussed how light from the sun can warm their skin and heat water. These effects were taken as suggesting a possible new type of energy: that carried by light. Two toys are given to students that allowed them to use their own energy to produce light: a simple dynamo and a flashlight that is activated by shaking. (The transparent case allowed them to see a magnet moving back and forth within a coil. The nature of the process was not explored in depth, but the students could make the connection between motion and the production of light, thus closing the loop with some of their earliest experiences).

Finally, different forms of internal energy were explored. The students saw that dissolving salt or sugar in water lead to changes in temperature. They reasoned that the change in energy of the water, reflected in the change in temperature, must be accompanied by changes in the energy of the dissolved substances. As in earlier cases, the pupils were encouraged to identify two interacting systems in the process. They then found that by manipulating plasticine both its temperature both its shape changed. Both of these effects were taken as evidence of changes in the "internal" energy of the plasticine. This notion was expanded through an experiment in which a wire was broken in three ways: cutting with scissors, heating over a flame, and weakening it to the breaking point by repeated bending. Evaporation was the next context. The process in which water was heated over a flame to the boiling point, evaporates, and condenses on a nearby surface was analyzed with respect to energy transformations. The students then had a chance to apply this analysis to a more unusual situation in which a thermometer was placed in cotton wool soaked in alcohol and the temperature was observed to drop. The temperature changes observed were taken as evidence of internal energy transformations.

The Path in Middle School

The path for middle school reorganizes the activities of the path for primary school, enlarging the parts devoted to simple quantitative experiments. It consists of fourteen inquiry-based activities focused on the recognition of the main energy types, starting from the energetic analysis of systems in free fall, to be followed by considering several other situations in which the potential energy of a system transforms into kinetic energy (rotational and translational), internal energy, and energy associated with light. Several systems used in the primary school path are used also in the middle schools, so we refer to the figures presented above.

An analysis of a free-fall process involving three different balls (one made of plasticine, one made of plastic and one for playing ping pong), was the basis for a preliminary exploration of different transformations that will be analyzed thereafter, in particular those involving different types of collisions with the floor. The analogous behavior of the three balls in free fall allowed students to share the idea that all balls acquire kinetic energy while falling and that the initial action of changing height provided the needed energy.

In order to analyze the energy involved when identical balls are released from the same height, balls were dropped into a box filled with flour (Figure 2). The deepness of the crater created by each ball constitutes a visual, qualitative indicator of the amount of the ball's energy. Free fall from different heights allowed students to recognize the role played by the difference in level.

From the comparison of the depth of the craters made by falling balls of different mass, students could recognize that the energy of the falling ball also depends on its weight. Simple proportional reasoning lead to the conclusion that the energy must depend on the product of the ball's initial height and weight.

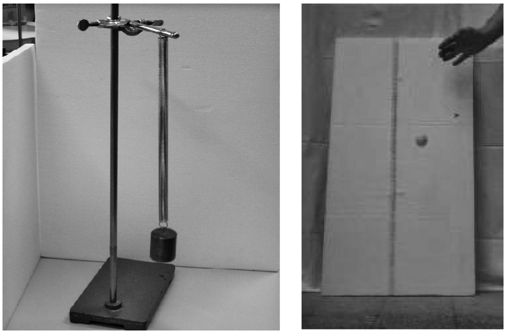
A quantitative study of the height to which a ping pong ball rebounds leads to a discussion of successive energy transformations (Figure 4).

Newton's cradle served as the context for the analysis of other collision processes. The qualitative and quantitative observation of oscillations in which only one ball moves provided the opportunity for recognizing that the falling energy, which subsequently will be named gravitational potential energy, is only associated with the difference of level and not with the path followed. The recognition of the fact that in Newton's cradle the first and the last balls reach the same height in the initial oscillations helps build the meanings of transformation, loss and conservation of energy.

In addition to exploring how the gravitational potential energy transformed into other types of energy, pupils were encouraged to find ways to lift the ball, i.e. ways to give it gravitational potential energy. For this purpose, a toy to launch balls upward was used (Figure 3a). By means of simple quantitative measurements, the students observed that the height reached by a ball was well-defined once the initial compression of the spring was fixed, illustrating the transformation from elastic potential energy, initially introduced as energy of the spring or elastic energy, to gravitational potential energy.

When this toy was in a vertical position, the inverse transformation can be performed. The spring was "charged" by simply putting a mass on it: gravitational potential energy was transformed into elastic potential energy (Figure 4).

Figure 4



The spring-mass system set-up and the bouncing ball

The yo-yo game allowed students to continue the exploration of energy, in particular recognizing the role of the hand in re-establishing the energy of the yo-yo, and introducing rotational kinetic energy.

Energy was analyzed using an upturned bicycle on which the posterior wheel is put in rotation by pushing on the pedals. The bicycle constitutes a compact palextra for exploring transformations of different types of mechanical energies, but also for recognizing that mechanical energy transforms to internal energy when the wheel is stopped by rubbing it with a hand.

The use of a dynamo offered the opportunity for exploring, by means of a bicycle, an energy transformation that involved the energy associated with light.

The dynamo of the bike stimulated a discussion of how it is possible to use rotational kinetic energy for practical reasons. Other situations in which rotational kinetic energy was involved provided opportunities for consolidating and generalizing the concepts: the turbines of windmills activated by the wind or the water; the led activated blowing on a fan/electricity generator; an electrical torch supplied by an oscillating magnet generator.

The analysis of different situations in which external energy was transformed into internal energy of a system concluded the path: salt and sugar were dissolved in water (internal energy associated with chemical bounds); evaporation, fusion, the molding of a piece of plasticine (as examples of internal energy changes associated with structure changes); heating of a system (internal energy changes associated with temperature changes), and iron wire cut or broken via mechanical stress.

The Path in Upper Secondary School

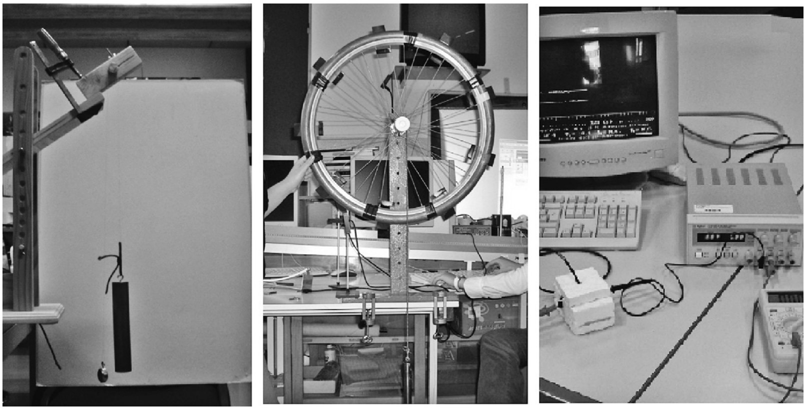
In our proposal, the unitary nature of the different types of energy is made explicit by analyzing the transformation of each type of energy into the internal energy of a system (an aluminum cylinder) (PS2, 1972). We reach this goal through experiments carried out with quantitative measurements performed using sensors connected to a computer. The quantitative measurement of the temperature increase of the aluminum cylinder with a thermal sensor interfaced with the computer is related to the variation of the internal energy of the cylinder. The measurement of the increase of the internal energy of the aluminum cylinder in the different cases gives accurate results about the net energy balance involved. However, the thermal inertia of the heated system, allows only qualitative evidence of the real-time evolution of the energetic processes occurring.

We developed a set of experiments that provide the opportunity to follow two different paths: a first, more traditional path, starts from the work-kinetic energy theorem; the second, less usual, introduces energy in the context of thermal phenomena. Here we briefly outline the main steps of the second one.

The background for the second path is the thermal interaction of systems, analyzed from the perspective of the Fourier thermal equilibrium law. The heating of different masses of water and then of water and oil permits the introduction of an operational definition of heat as the product of the mass of the heated system, the specific heat of the material, and the variation in temperature. The opportunity to heat the same body (the aluminum cylinder) by the same amount of energy in different ways (heating, by rubbing, irradiating with a lamp) shows that in all cases we are changing a property of the system, that is the internal energy of the aluminum cylinder.

The change in the potential energy of a falling object is then explored by fixing the cylinder to a vertical support with a thread wrapped around it (Figure 5). One extremity of the thread holds a bucket full of sand or a brass cylinder of fixed mass, while at the other extremity there is a small weight, in order to adjust the (constant) velocity of the fall of the bucket. The number of coils of thread around the cylinder are chosen to allow a slow motion of the bucket, making negligible the kinetic energy of the moving masses with respect to the variation of gravitational potential energy. The mass of the falling system and then their height are changed to discover how potential energy depends on each of them and then on their product. When the falling system is put on a cart on an inclined plane it is possible to see also that the potential energy depends on the vertical projection of the falling path.

Figure 5



The apparatuses to study the transformations of energy in internal energy of an aluminum cylinder using sensor on-line with computer, in upper secondary school

The falling mass (a brass cylinder used earlier) is used to put into rotation a bicycle wheel, uniformly loaded on the rim with lead, and constrained to rotate horizontally around its hub. A thread is fixed to the hub and then rolled, with the free extremity holding a suspended mass m. When this mass is free to fall, the wheel starts to rotate, until the falling system reaches the ground. At that instant, the usual aluminum cylinder is used as a brake, pushing it into a cavity of the wheel's hub (Figure 5). The velocity acquired by the wheel can be measured using a photogate. Also in this case students can change the height and the mass of the falling system. It is very simple to discover that the kinetic energy of the wheel depends on the square of its speed and is proportional to its mass (a more sophisticated treatment can include the rotational inertia but for a first approach it is sufficient assume all the mass is concentrated on the outer rim of the wheel). The energy transformations involved in this process are therefore two: from gravitational potential energy of the suspended mass to rotational kinetic energy of the wheel and from this latter to internal energy of the cylinder.

Elastic energy can be introduced by rolling around the aluminum cylinder an inextensible nylon (or better, Teflon) thread. One extremity of the thread holds a weight, while the other one is tied to an extremity of a spring, fixed to a support. Starting from a situation in which the spring is forcibly extended, the system relaxes to an equilibrium configuration, contracting the spring and raising the weight. The correlation between the elastic potential energy and the square of elongation of the spring is discovered in this way. Its correlation with the elastic constant is recognized using different springs

In subsequent steps the transformation of energy associated with electric current is considered. The aluminum cylinder is thermally insulated inside two polystyrene blocks and then heated by means of a small resistor inserted in a little hole in it. Measuring both current and voltage is possible to discover that the heating power depends linearly both on the current and on the voltage, and thus their product. This experiment bridges to an analysis of a bicycle lamp powered by a dynamo, discovering that a part of the energy involved in the bicycles movement transform into energy associated with light. The heating of copper by different sources of light is the basis for discovering the parameters that influence this process.

Research Experimentations in School: Context, Instruments and Methods

The path for primary school was tested in a pilot class by a teacher. The entire sequence took 20 hours and involved a group of 22 students (12 female, 10 male) 8 years old (K4). The students were given a pre-test and a post-test, which are discussed below. During the activity they used a worksheet organized as follows: a problem, the exploration of a situation that can provide an answer to that problem; the construction of the conceptual micro-step activated by the exploration.

The path for middle school was tested in six hours intervention module, plus a one-hour post-test, carried out by a researcher. The first eleven steps of the path described above were used in a third level class in a middle school in Udine (K8), composed by 19 pupils (aged 14). The sample analyzed here included 16 students (9 female, 7 male), who attended the entire six-hour module of activities plus one hour for final tests. Five students were not native Italian speakers, and three of them had clear difficulties in understanding and writing in Italian. Also in this case, students used tutorial and a pre/post-test. The test used for the primary and middle school students have a common first part.

The path for high school was explored in an un-systematic way so we do not include any discussion of results here.

Methodologically this study represents an experimental research projects.Primary and middle school pupils who participated in the paths described above were given both pre-tests and post-tests. In this section we discuss their responses to the following questions of the questionnaire, which are in common in the two experimentations:

- Q1. What do you know about energy?

- Q2. As far as you know, are there things that make energy?
- Q3. As far as you know, are there things that have/possess energy?
- Q4. Is energy conserved? In your answer explain in what is meant by "conserved".
- Q5. Can energy by transformed? Explain, giving two examples.
- Q6. Can energy be lost? Explain, giving two examples.
- Q7. What types of energy do you know about?

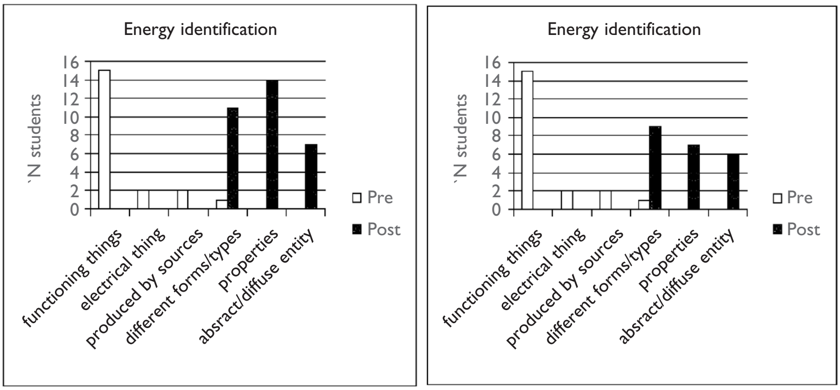
The responses of the questionnaire provide insight into the student's ideas and ways of thinking about energy and help us to identify conceptual "knots" that they will struggle with. The responses were analyzed at different levels and in different phases: identifying and counting the concepts, and determining frequencies for the categories, emerging from the data. In some cases statements falling into two categories were obtained from a single student. For the purposes of counting frequencies, however, each student was assigned to a particular category according to his or her prevalent view.

Results and Discussion for Primary Pupils

Here we summarize data obtained from 22 8-year old pupils who followed the path described above.

Q1. *What do you know about energy?* On the pre-test, energy was identified as "what makes things function" (15); an "electrical thing" ("cosaelettrica") (2); "what is produced" by sources (2); or by the different forms it takes (1). The examples mentioned were: light (9) and electricity (2). In the post-test energy was

Figure 6



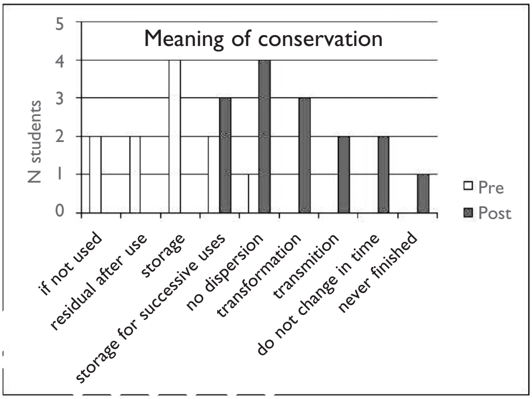
Results in primary from Q1 (non-exclusive on left, exclusive on right) identified with: (A) different types related to different sources (9), internal, kinetic, potential forms (4), and light (2); (B) its properties of transformation (5), conservation (1), or transfer (1); or (C) an abstract (5) or diffuse entity (2). See figure 6 for a summary, where the two distributions of the exclusive categories are statistically different (x^2=38, p<0,0001).

Q2. *As far as you know, are there things that make energy?* On the pre-test, 19 pupils answered only "Yes," citing water (7), wind (5), turbines, the sun (3), "electricity" (3), and batteries (2). On the post-test all pupils formulated answers using the verb "make" (20) or "produce" (2), adding examples explored in the path [turbines (5), body-spring systems (3), or Newton's cradle (2)].

Q3. *As far as you know, are there things that have/possessenergy?* On the pre-test, 16 pupils said yes and cited (A) domestic electric items (6) [light (4), light bulb (3), batteries (3), and toys with batteries (2)]; (B) minerals (1), fire (1) and mechanisms (2). The 22 positive answers on the post-test refer to the wide spectra of systems considered during the activities, attributing energy to the human body (9), human foot (5), objects containing a spring (5), all systems and bodies (4), Newton's cradle (2), magnets (2), and bicycles (2).

Q4. *Is energy conserved? In your answer explain in what is meant by "conserved."* On the pre-test the 14 answers were: energy is conserved always (9), sometimes (3), never (5), when it is used (2), or when it is consumed (1). The meanings of conservation/ conserved expressed were related to: storage (4), for successive uses (2), if not used (2), not dispersed (1); residual energy left after use (2). On the post-test 19/22 asserted energy conservation, with the following motivations: it is transformed (4), transmitted (2), lost (1), accumulated (1), and

FIGURE 7



Meaning attributed to "conservation" in pretests and post-tests in primary used (1). Examples given were mainly collision processes (Newton's cradle and bouncing balls) and the forms of internal energy considered in the path. The 17 meanings of conservation expressed were: not dispersion (4); stored for successive uses (3), energy not lost only transformed (3) energy not lost only transmitted (2); energy does not change in time (2) and energy is never finished (sun energy) (1). The idea of energy conservation was vague and local, related to specific experiences: bouncing ball, Newton's cradle and the motion of a body-spring system. Figure 7 shows statistically significant changes in the meaning of energy conservation from pre-test to post-test (x^2=17.8, p<0,05).

Q5. *Can energy by transformed? Explain, giving two examples*. On the pre-test the 10 answering pupils stated that energy can be transformed, quoting a specific change from a form to another (2 of them – i.e. from nuclear energy to electric energy), exemplifying change from an initial entity to energy (3, i.e. "wind transform in energy", "water-fall make energy, but man transform it", "energy transform in electricity"), reporting just a form of energy (1, hydroelectric) or one or more systems (3, i.e "windmill", "the water on the heater"), or without any specification (2)… Some gave no arguments or examples. Others said that some entities become energy (i.e: wind becomes energy), some actions produce energy (i.e: waterfalls produce energy), energy is transformed into electricity. Energy transformations were related to the sun, electricity, hydroelectric energy. On the post-test, the all the 212 pupils who asserted that energy can be transformed, exemplifying transformations from a type to another making reference to the systems analyzed during the learning path (17 referred to i.e. "If the object is above is potential energy, if it is half is kinetic energy"; "If you push a wheel with one hand, the internal energy transform into rotational kinetic energy"; "The ball and the spring: internal en. → kinetic en. → potential en"; "In the example of the bicycle: rotational kinetic energy → electrical energy in the dynamo"; "In the example of the ball falling on the floor: potential falling energy → kinetic energy → internal energy of the floor and of the ball"), quoting the types of energy "used" (1), quoting phenomena or systems (2) or with any specification (1): changing the form (15), starting motion (2), changing elements within the systems (2), or gave specific examples (1). 20 pupils gave one or more quoted examples of energy transformation are: from kinetic to internal energy (12), from potential gravitational (10) or elastic (2) to kinetic energy and vice versa. And from kinetic to electrical energy (2). They chose as contexts: the bouncing ball (14); systems with a spring (7); the, bicycle (6), turbine (2), dynamo (2), and Newton's cradle (1). A significant change emerge from pre/test to post/test: before the educational path the large majority of students do not answered, and the answering students most often cited transformations of an entity (wind, electricity) into energy, or quoted processes at all not related to energy and in only two cases cited examples of transformations from a form to another one; In summary, at the end of the educational path, the physicist's way of thinking was adopted by 757% of pupils.(17/21) explicitly specified that energy transform from a type to another one being also able to propose one or offently more example referred to the situations explored during the educational path, in particular including potential energy and internal energy, that literature evidenced as problematic forms (Duit, 1987; Carr & Kirkwood, 1988; Brook & Wells, 1988).

Q6. *Can energy be lost? Explain, giving two examples*. On the pre-test only the 10 answering pupils answered. Nine said that energy can be lost, in 9 cases with examples: "If we leave the light on," by "walking,", "in a nuclear center explosion," or "if not preserved in a specific box.". On the post-test, 21 all the 22 pupils answered, in the majority of cases saying that energy cannot be lost (17), [because it transforms (9) or transfers (8)], or do not giving explanation (4), and just in 1 case answering positively that we can have dispersion (4). Also in this case the examples quoted were the same as those mentioned previously. An important change in point of view from pre-test to post-test is seen in the motivations and examples that explored during the path. (17/21) pupils wrote using experience gained in the path.

Q7. *What types of energy do you know about*? On the pre-test 17 pupils named types forms of energy associated with sources [electrical (12), hydroelectricity and nuclear power (4-5), internal energy (1)], systems [the sun (6), wind (4), the human food (12)], entity and internal energy (1), [wind (4)]. On the post-test all the 22 pupils quoted named only types of energy [kinetic and potential energy (20), internal energy (3), light energy (2), elastic energy (2)]. A form is quoted just in a case (body energy). Additional evidence of conceptual growth can be found in increased precision in the use of language and an increase in statements reflecting a scientific point of view. Discussions of concepts are less local on post-tests than on the pre-tests but still tend to be connected to concrete experiences from the path.

Discussion of the Data for Primary School

From data obtained on Q1-Q7 on both pre-tests and post-tests emerge an important change of ideas among the pupils who worked with the described path. In particular their ideas became more clearly defined, thanks to the increasing richness of answers in post-test in comparison of pre-test (70%).

On the pre-test the prevalent idea about energy of pupils is local and functional apparatuses. The post-test shows that an operative definition of energy emerges (75%)

through a small number of types, coherent with the scientific point of view, mainly with regards to the properties of energy (transformation, conservation, abstract nature and types).

Before the path, pupils had the common sense idea that a system "makes energy." After, they express the idea that sources are systems in which energy transformations occur and this is what "to make energy" means for pupils (90 %).

Pupils developed the concept that all systems have energy and are able to attribute the specific form of energy to a wide number of systems considered in the path (86%), overcoming the previous idea that only (electrical) apparatuses have energy.

In the path the idea of energy conservation was mentioned, but only in a qualitative way for the cases of a bouncing ball and Newton's cradle. Therefore it is not surprising that a vague idea of conservation is present on the post-test. It is however interesting to note a shift in process analysis in ideas toward the idea of transformation and transmission of a constant (not dispersing) and indefinite property. That energy cannot be lost, but transformed and transferred is another important point of view expressed with competence by 70% of pupils on the post-test compared to the percentage confused or holding the opposite opinion (50%) before the path.

The number of pupils providing more than one energy transformation example increased from pre-test to post-test. More students were able to specify the energy transformations involved in processes. We also have evidence of a "physics" way of thinking adopted by the majority of pupils after the path. The situations and processes they experienced are detailed in terms of energy transformations. After teaching, the human body and human foot become less relevant than games (bouncing ball, toys with springs, etc) in which they are able to discuss energy processes.

Results and Discussion for Middle School

Pre-test data analysis

The pre-test data analysis is here presented for what concern items Q1-7, related to the general idea of energy, and Q10-12 e Q16-17, concerning specific situations explored in the classroom activities and documented also with the analysis of the work-sheets. Here and in the following: the number of students in our sample (N=16) that gave an answer or wrote a statement is indicated in parentheses; NA indicate no answer at all.

Q1. *What do you know about energy?* Energy was identified: by the different forms it takes (2); as a force (2); as the capability to do action/movement (3); capability to do work, produce electricity, keep still (1); by usefulness for the world" (1); NA (7). Each of the following forms is cited only a time: kinetic, potential, thermal, chemical, solar, nuclear.

Q2. *As far as you know, are there things that make energy?* Yes (10), quoting systems as the sun (5), water or wind(3); batteries (2), food (2); lamps (1); No, because energy can neither be created or destroyed,it is transformed (4); NA (2)

Q3. *As far as you know, are there things that have/possess energy?* Yes: 11 [having energy=it transforms or it transfers (2); all bodies (2); the sun (2); the batteries (2), lamp (1), foods (1); car (1); magnets (1)]; NA: 5.

Q4. *Is energy conserved? Explain.* Yes (7), it transforms (2), if not used (2), in the batteries (2) in power centrals (1); No, it is lost (1); NA (8).

Q5. *Can energy be transformed?* It transforms from a form to another (7); in the transfer from a body to another (2); energy becomes a system (1); NA (6). Examples: transformations of thermal/chemical energies (8); machinery (3)

Q6. *Can energy be lost?* No, it is not lost, but it is transformed (3); It is lost, because it is transformed (1), NA (11).

Q7. *What types of energy do you know about?* Kinetic (15); potential (3); mechanic (5); gravitational (6); thermal (14); electrical (10); magnetic (2); chemical (7); hydric (5); radiating (2); solar (10); nuclear (12); eolic (1); NA (1).

Work-sheets data analysis

In the following the analysis of answers to 2 work-sheets used in the path is reported.

Work-sheet 1 – The potential falling energy

In analyzing the situation in which the three different balls (plasticine/plastic/ping-pong balls) are lifted at a certain height and then released in free fall to the floor, to the requirement of identifying the type of energy possessed by the falling plasticine ball, the students answered: “kinetic” (11), “potential” (2), “energy” (1), NA (2). The association of the kinetic energy to a moving body is almost spontaneous,

When the students are requested to compare the plasticine ball case and the plastic ball one, they gave the following answers typologies to the question: “What are the differences in the energy transformations?”: T1A (3): Distinction of the energetic process involved in the impact (“the transformation is kinetic and potential”, “energy is not muffled”); T1B (5): only an energy form, or a specific energy process, without distinguishing the two cases (“it becomes kinetic”; “kinetic-gravitational-kinetic-gravitational”). T1C (1): different falling energies; T1D (1): Description: “a ball stops, a ball moves”(1); T1E: NA (6).

As far as the energy of the ping-pong ball hitting the floor is concerned (Dawson & Stein, 2008) the students statement typologies were: T2A -energy-like (10): “a part of the energy passes to the floor” (4), “the energy decreases (3), “the energy becomes potential” (1), “at the impact the energy of the ball does not increase anymore” (2); T2B - force-like (2): “great velocity great weight”; T2C-description (1): “at the impact it bounces”; T2D: NR (3).

The successive requirement is to make explicit a hypothesis about what happens to the ball energy after bouncing on the floor, the following topologies of answers were found: T3A (7) - energy like interpretative hypothesis, associating energy to the system sometimes [T3A1 - energy decreases, it is re-absorbed by the ball (5); T3A2 – energy transformation (2)]; T3B (3) - force-like interpretative hypothesis: "it is repulsed back in the air"; T3C (2) – different material explanation ("the ball bounces more time because of the different material it is made"); T3D (4) kinematical description: "the height/velocity decreases" (4). The students adopted force-like or energy-like explanations according to the context and therefore different students are classified as T2B or T3C.

To the requirement of analyzing the decreasing height of the ping-pong ball re-bouncing and of making explicit the different energy transformations involved, all answered used only the concept of energy: T5A- Different energies associated to different phases (1): "Potential, kinetic, potential"; T5B- energies involved in the net transformation (2): "gravitational potential", "kinetic"; T5C-energy associated only to one of the involved processes (5): during the falling potential energy (1) or kinetic (2); gravitational/potential at the impact (2); T5D: NA (8).

Then students were requested to indicate "the types of energy that the ball has" in the points: A, from which it starts falling; B, at the first impact with the floor; C, at the maximum height of the first bouncing; D, at the second impact. The answers typologies were: T6A (2): gravitational-kinetic-potential-kinetic; T6B (3): kinetic-potential-kinetic-potential; T6C (3): potential-potential-kinetic-potential; T6D (1): it falls-hits-returns up-falls again; T6E (6): NA. The analysis of phenomena subdivided in phases allows to recognize the single processes, favouring the identification of energy forms involved in each phase and the constructing of a picture more and more coherent (2/3th of the sample).

Work-sheet 6 – The Newton's cradle (moving only a ball)

As far as the requirement of "describing the observed motion of the pendulums" (the Newton's cradle) is concerned, we found the following typologies: T8A - energy transmission descriptions (6): the ball in the middle "transmits the energy"; T8B - force/momentum like descriptions (2), as " the sphere on the left transfers force/motion to the sphere on the right"; T8C - kinematic description (7): "the pendulums oscillate"; T8D (1): NA. Some pupils specified: "the motion continues" (2- stressing on the persistence of motion), or the process continues "until the energy finishes" (3- stressing on dissipation).

When students are requested to reconstruct "the energy transformations", only energy-like analyses emerged: T9A (6): cyclical transformation of energy: potential, kinetic, potential, kinetic; T9B (5): only a process, the one implicitly assumed as the more relevant: "potential-kinetic" (3); "potential-mechanic" (1); "kinetic–potential" (1); T9C (5): NA. The quantitative analysis of the process, using an optical projection method to detect the displacements of the first and the last balls, directs most of the students (14 against 2 NA) to declare that energy, acquired by the last ball, is equal to energy, initially possessed by the first ball, explaining that: "at the first throw, energy is the same" (4); "at the first throw, energy passes to the second (ball)" (3); energy is transported (2); "the height is always the same and the energy is equal" (1); "the forces are equals" (2); NA (4).

Post-test data analysis

The post-test data are reported in this paragraph, concerning items Q1-Q8, Q10-12, Q16-Q17 (the same as in the pre-test).

Q1: Energy is identified by: the different forms it takes (4); the characterizing properties [6-transformation (4), conservation (2), the fact of being in the systems (3); a force (3)]; capability to make actions/movement (3) and work (1). NA (6). In terms of mutually exclusive categories the identification occurs: recalling the properties (6) and/or specifying the existence of different forms (5) (tot.8); associating to the capability of making work/movement (2); quoting specific energy forms (3); kinetic (3); potential (2); mechanical (1); elastic (1); gravitational (2); work (1); thermal (3); electrical (3); chemical (1).

Q2 – Yes [13- quoting following systems: the sun (3); the human body (2); the fire (1)]; No, because it is transformed (2); NA: 1.

Q3 – Yes [13 – all bodies (8), when they have a specific position (3) or are moving (2), only in a case the mill is re-called as an example]; NA (3).

Q4 – Yes [8 – it cannot be depleted (1); it is transformed (4), as in the machineries (1); only sometime (2)]; no, it disperses (2); NA (7).

Q5 – It is transformed from a form to another (8); it is transformed (3), NA (5). Examples: potential→kinetic (5); gravitational→elastic (1), kinetic→rotatory (1), chemical→potential (1); solar→thermal (2); hydraulic→electric (1).

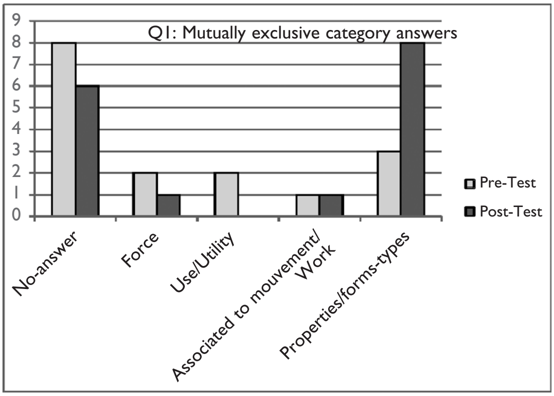
Q6 – It is not lost, it transforms (3- the same as in the pre-test); yes, it is lost [6 –when it is transformed (1)], it is dissipated 4 [in the environment, in the air (3), in the interacting systems (3)]; NA (3). Examples: Newton's cradle (5), the ball falling on the floor (3), the bicycle (1), the guitar string (1).

Q7 – kinetic (15); potential (14); mechanic (10); elastic (10); rotatory (2); gravitational (1); work (1); thermal (4); chemical (4); eolic (2); magnetic (1); solar (1); nuclear (1); hydric (6); muscular (1).

Comparison of pre-test and post-test data and discussion

In Figure 8 are reported the categories related on how students identified energy in the answers to Q1 question, where significant differences emerges (x^2=4.9, p<0,5). The answers given in the post-test are more rich and specific in making explicit aspects of the scientific conception of energy. For Q2 and Q3 the answers are mainly affirmative, with significant changes in Q3 in relation to the identification of energy as a property of all systems (from 2 to 8 students).

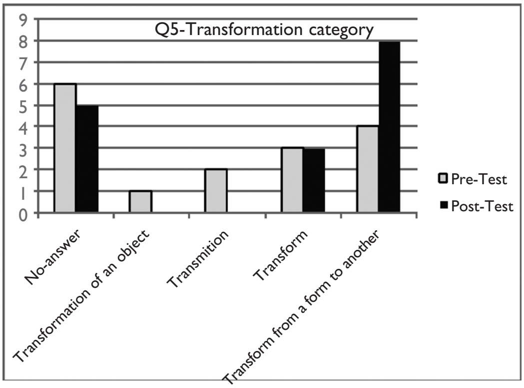
FIGURE 8



Q1 - Energy identification categories in middle school

Figure 9 shows a shift towards Q5-categories in which energy transformation is referred to a change from an energy type to another (x^2=4,4, p<0,5). In the pre-test, among 10 examples proposed, most of them are cases in which thermal and chemical energies are involved (8), without identifying or associating them to specific systems.

FIGURE 9



Q5 - Energy transformation categories in middle school

In the post-test, the 11 indicated transformations are contextualized in the examples used in the path (free fall of an object, pendulum, bicycle) and the potential energyúkinetic energy transformation prevails (5).

Regarding the meaning of Q6-energy loss the proposed activities favored the anchoring of argumentation to well specific situations. Regarding the quoted energy forms in Q7 a significant change about the potential energy emerges.

Conclusions

In spite of the social, scientific and technological importance of the topic energy, an agreement on how to face such a topic in the school is missing. Moreover energy is treated in school with different approaches not only in physics courses, but also in relation of science and social topics, without unifying elements that can help to identify energy in the different contexts as the same entity. There are many proposals of educational activities and materials that have already been proposed in order to clarify single aspects of the topic (Dahnck et al., 1973; Falk et al., 1983; Duit, 1984; Brook & Wells, 1988; Carr & Kirkwood, 1988; Duit & Haeussler, 1994; Boohan & Ogborn, 1996; Goldberg et al., 2010). Despite the attention on how produce inquiry based strategies on teaching and learning energy, not consensus was reached in the rationale and on the following aspects: how identify the concept of energy; meaning of expressions like transformation, conservation, and dispersion of energy. The main problem is the cultural and pedagogical coherence of a curricular proposal. It emerges the need of a curricular vertical perspective to achieve the gradual appropriation of the synthetic vision that the concept of energy required to give a new language in scalar terms for the interpretation of phenomena, connecting at the same time the multi perspective vision of the various subjects in this field.

Many pupils associate energy to specific systems (living beings, batteries, energy sources) or processes (human activities, explosions, combustions), have difficulties in the recognition of potential and internal energy and, in general, do not associate energy to a motionless system. Moreover, students have difficulties to identify energy and distinguish it from other physical quantities (i.e. force or power).

A research based educational path has been designed in vertical perspective for a coherent subject curricular proposal on energy, from primary to secondary school (Energy Vertical Path). Following also the suggestion coming from other authors (Duit 1984; Brook & Wells, 1988; Carr & Kirkwood, 1988), a first assumption was that context analysis of every-day live processes favors the identification of the different types of energy involved and helps the recognition of the energy transformation involved. Moreover, we supposed that discussions in context about the meaning of storage and dispersion of energy create the bridge between common language and scientific one if the critical way of looking the processes in terms of energy is adopted in many different situations, becoming a way of thinking in parallel of those in terms of actions. On the contrary, we avoided discourses in terms of energy forms, because this inhibits the clarification of the energy types (kinetic, potential, internal and associated to light) that are usually used in physics.

The primary goal of the Energy Vertical Path is to help pupils move towards a more scientific conception of energy that can be further extended and refined in subsequent educational levels. In particular, the path aim the concept of energy as a physical quantity associated to a system in a well-defined condition (property of state), that can transform in different types. As well as promoting the acquisition of ideas specific to the topic of energy, the path is designed to promote scientific thinking.

The strategy of the path is to analyze concrete situations linking energy types and physical systems and conditions. The aim is the reconstruction of pupils' ideas toward a scientifically oriented conception of energy, able to favor future developments.

A context related approach and inquiry based strategy inspire the suggested vertical educational path, experimented both in primary and middle school and both in prospective primary teacher formation. The rationale of the energy vertical path introduces types of energy (kinetic energy, potential energy, internal energy and energy associated to the light) having as a referent the falling energy (weight multiply by the difference of falling height) in different situations. In primary school the approach considers the (internal) energy of human body, that constitutes a very natural context for pupils, as it emerges in literature and in our preliminary explorations. The focus is on the identification of the different types of energy in different contexts and how energy transforms from a type to another. The description of the processes both in terms of phenomena and with the language of energy becomes a way of thinking gradually constructed and improved.

In middle school, the systems that have already considered in the path in the primary, as the bouncing ball, the mass-spring system and the Newton cradle, are reanalyzed offering the opportunity to carry out simple measurements and to consider thefirst energy balances. In upper secondary school, different energy types are converted in internal energy of the same system as explorer, varying the different parameters to identify the formal expression of the energy types and the work done in different cases. The two ways to change the internal energy of a system, as stated in the first principle of Thermodynamics, are considered. The work-energy theorem is addressed in a successive exploration. Students use sensors on-line with computer to analyze processes, constructing energy-balances, recognizing and formalizing the different types of energy.

All the three levels of the energy vertical path are based on an inquiry strategy, implemented with tutorials for students. The first two parts has been experimented in pilot classes and a research, in the framework of Shulman's Pedagogical Content Knowledge (1987), has been developed with prospective primary school teachers, attending a formative module based on the first path. For what concerns the third path, for secondary school, only a preliminary test was carried out, and it is actually under experimentation. The students learning paths in primary and middle school during the energy vertical path activities are reconstructed analyzing three main sources: answers to the different questions contained in the tutorials, answers to the pre/post-test, interviews and notes of experimenter. The curricular choices made for the primary school produced in the learning of the majority of students: A) well-defined identification of the concept of energy, expressed through a small number of types and forms; B) competences in propose significant explifications of energy the processes analyzed during the educational path quoting the energy types involved and the related energy transformations; C) an use of energy language coherent with the scientific point of view, mainly with regards to transformation, abstract nature of energy and showing; D) some primitive nuclei about conservation. In middle school the main change emerge in the description of phenomena: before the path performed using a mixture of interpretative and descriptive plans in terms of actions, force, behavior; after the path the main part of the students described processes in terms of energy transformations, associated energy to systems, recognized the potential energy as a type of energy; reshaped their attitude from describing processes in terms of the concept of force to descriptions in terms of energy states and transformations. Some partial results were also obtained about the deep-rooted conceptions on "energy loss", reshaping students' attitude from an energy disappearance conception to an energy transformation way to look at phenomena, associating energy to systems, but also, in few cases, growing up a primordial idea of energy conservation.

The results common for the experimentations and the specific results characterizing the two analyzed cases, obtained from the analysis of the educational materials used in class, will be used to develop a revised version of the energy vertical path and extend the experimentation in school.

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