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Teaching Energy Conservation as a Unifying Principle in Physics

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Abstract In this work we present the design and assessment of a teaching sequence aimed at introducing the principle of energy conservation at post-compulsory secondary school level (16–18 year olds). The proposal is based on the result of research into teaching-learning difficulties and on the analysis of the physics framework. Evidence is shown that this teaching sequence, together with the methodology used in the classroom, may result in students having a better grasp of the principle of energy conservation.

Keywords Physics education · Energy conceptions · Teaching activities

Introduction

One of the main aims of physics is to interpret different phenomena in a unified form. The concept of energy allows such unification because it is a property that all systems have. Its conservation is a universal principle that is fulfilled in all fields of physics. On the other hand, energy plays an important role in other sciences such as chemistry, biology or geology. Mass media highlight the social importance of energy and everyday language uses energy concepts such as energy sources, energy crisis, greenhouse effect, global warming, etc.

Reasons such as those mentioned indicate the importance of students strengthening their learning about energy by means of specific skills in the principle of energy conservation, transference and degradation. However, various research into students' understanding of the concept of energy and the consideration thereof has revealed the existence of serious difficulties in learning. In particular, most secondary school students do not recognize energy conservation as a unifying principle of physics and do not use the concepts of energy transformation, transference and degradation (Duit 1981, 1984; Solbes and Tarín 1998; Tarín 2000).

The aim of this article is to present the design and assessment of a teaching-learning sequence in order to introduce the principle of energy conservation as a principle applicable to different physics contexts at post-compulsory secondary school education level (16–18). According to Meheut and Psillos (2004), we consider "teaching-learning sequence" as a term to denote the link between the teaching proposed and the learning expected from the student. In this work we have raised the following research questions:

- How can we design a sequence of activities to help students understand energy conservation as an all-physics concept and increase their interest in learning physics?
- What do students learn after the teaching sequence has been introduced into a class? In particular, after implementing the sequence, would students recognize energy as a property of a system and would they identify work and heat as an energy transference

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process? Would students apply energy conservation as a law applicable to all phenomena and would they recognize the degradation of energy?

To answer the research questions, firstly, we carried out a revision of previous research on students' difficulties in learning the concept of energy. In the following section we present a summary of the findings in previous researches. Secondly, based on these findings we developed a teaching sequence focused on the understanding of the principle of energy conservation. The sequence was tried out in the classroom. Following the description of the teaching sequence, we will present findings from a classroom trial on the progress in students' understanding of the principle of energy conservation applied to different areas of physics.

Previous Research on Students' Explanations of the Concept of Energy

During the last 20 years there has been intense educational research on the learning and teaching of energy. Firstly, students' difficulties were analysed. Research results show that students identify work and effort (Driver and Warrington 1985), energy and power (Goldring and Osborne 1994), consider only one of the factors that form part of work and forget the other, identify work and energy (Duit 1984; Driver and Warrington 1985), assign a material character to energy (Duit 1987; Solomon 1985), associate it with movement, activity (Solomon 1983) or processes (Duit 1984; Viglietta 1990), consider that energy can be used up (Kesidou and Duit 1993) or stored (Solomon 1985) since everyday language is impregnated with expressions such as "consumption of energy" or "energy crisis", attribute gravitational potential energy to a body but not to the interaction between two bodies (Solbes and Tarín 1998), ignore internal energy changes (van Huls and van den Berg 1993), think about heat in terms of a substance (Albert 1978; Erickson 1979, 1980), and confuse heat and temperature (Arnold 1994; Labur and Niaz 2002). More specifically we identified the following aspects:

- Students have a polysemic understanding of energy that does not usually agree with scientific understanding. Most students identify work or heat with energy Doménech et al. 2007).
- Students confuse forms of energy with its sources (Car and Kirkwood 1988; Solomon 1985; van Roon et al. 1994; Trumper 1998).
- Students do not activate schemes for transforming, conserving, transferring and degrading energy without which this concept or the conservation principle cannot be understood (Duit 1981, 1984).
- Most secondary education students do not use energy conservation to explain simple phenomena in all fields of physics. Moreover, transformation or degradation of energy was seldom used (Solbes and Tarín 1998).

Design and Implementation of the Teaching Sequence

In relation to the first research question, the analysis of content and the results of research into students' conceptions were taken into account and we drew up a series of design criteria. These criteria allow us to sequence the main steps to be taken and stages to be worked through by students. In this paper the following criteria can be distinguished.

Firstly, clear comprehension of the concept of energy implies recognizing that the transformations that a system undergoes are due to interactions with other systems or to interactions among its parts; in other words, they are due to the capacity of matter to interact in different ways (Arons 1999). The idea of energy as capacity to cause change (Trumper 1997) led us to design a sequence which does not start from the theoretical knowledge about dynamical problems, as is usual in textbooks on this topic. Instead, in order to tackle the problem, a series of empirical generalizations is first developed, in the following terms: (1) Work is described as a process of changing matter by means of forces and, in this way, may be related to variations in energy. So work is conceived as a form of energy exchange; (2) Heat is not a form of energy but an exchange of energy between the particles of the system and the surroundings. The energy of the group of particles in the system may be included in the concept of internal energy (Arons 1997). These aspects are sufficient to learn an energetic model of interactions among systems.

Secondly, the development of the energetic model of transformations deals with the standard problem of explaining the conservation of an isolated system and the energy degradation as a consequence of transformation of a system (Duit 1987; Brook and Wells 1988). These problems were addressed in the sequence by the following terms: (3) The conservation of $W + Q + R = \Delta E$ as a general expression of the conservation of energy is valid in all areas of physics (Alonso and Finn 1992). The principle of energy conservation cannot be derived from the laws of dynamics and it is an independent statement (Arons 1999; Truesdell 1968). Moreover, energy variations may take place, not only through work or heat, but also by means of radiation exchange processes, but the principle of energy conservation is still valid; (4) As a result of the interactions and consequent transformations of a system, energy degrades. But this does not mean that energy disappears,

Table 1 Teaching objectives and learning difficulties

Teaching objectives	Learning difficulties
1. Recognizing energy as a property of a system	Associating energy with movement or activity
2. Identifing work and heat as a process of transferring energy from one system to another	Identifying work with effort
	Identifying work with its operational definition
	Identifying heat with temperature
3. Classifying different forms of energy as kinetic or potential. Recognizing gravitational potential energy as energy due to position or arrangement of an object with regard to the Earth	Identifying the forms of energy with their sources
	Associating gravitational potential energy with a single object
4. Recognizing energy is transformed	Analysing phenomena in terms of perception without considering energy transformations
5. Establishing the limitations of the conservation of mechanical energy	Ignoring transformations of mechanical energy into internal energy
6. Recognizing the degradation of energy as the transformation of mechanical energy into heat	Identifying the transformation of mechanical energy into internal energy as a waste of energy
7. Applying the conservation of energy in the interpretation of socially important phenomena such as energy crises and the use of renewable energies	Not recognizing STS relationships
8. Identifying the principle of the conservation of energy as a law applicable to all phenomena	Limiting the validity of the principle of the conservation of energy to mechanical and thermodynamic phenomena

and the apparent contradiction between 'energy conservation' and the 'need for energy resources' disappears (Ogborn 1986); (5) Technological applications and social implications. These aspects are sufficient to recognise the potential importance and interest of the study of the principle of energy conservation.

An example of how the criteria mentioned above can be taken into account is displayed in Table 1.

Principal Aspects of Implementation in the Classroom

The teaching approach for a group of activities which has the same objective, consists of a four-phase process that we call "science teaching based on developing guided research" (Furió-Mas and J Furió-Gómez 2008; Guisasola et al. 2008):

Phase (1) *Social implications of the problem*, in which an effort is made to make the problem interesting for students, so that they become involved in the solution. In addition, it makes them aware of the objectives being proposed.

Phase (2) *Analysis and group work*, this is a complex phase which involves producing hypotheses with suitable criteria, using imagination and creativity, and coming up with possible problem-solving strategies. Students working in small groups evaluate their individual ideas, add new ideas, and reach a consensus or disagreement.

Phase (3) *Teacher's guidance and class discussion*, the teacher guides an approach based on asking questions and on developing guided research. This approach places students in such a position where they are able to extend their knowledge and abilities in a certain direction which contributes to solving the problem. The representative of each group presents the group's consensus; all ways of solving the task are discussed under the guidance of the teacher and a classroom summary is formulated.

Phase (4) *Individual report*, in which each student individually accounts for the solution of the problem with a specific explanation of the stages of the solution. He/she reports what is learned and what still remains unclear (if anything). In the following lesson the teacher discusses the students' reports.

Description of Classroom Activities in Relation to the Sequence

The teaching sequence we presented here was structured in activities which were organized in the unit of energy and in different units over the last years at high school (17–18 year old students) in the Spanish secondary education system (Solbes and Tarín 2004; Tarín 2000). As an example, we are going to show some activities for two different parts of the sequence. The first example of activities is situated at the beginning of the sequence for discussing problems of energy transformation, transference and conservation (objectives 1–5 in Table 1) and STS relations (Chedid 2005) (objective 7 in Table 1) with students simultaneously.

Activity 1 Make a list of the main sources of energy, stating whether they are renewable or not, consumption thereof, etc.

Activity 2 Monitor all news connected with energy in the press for the time indicated by the teacher. Prepare a file of the news in order to discuss the social, economic, environmental technological consequences etc. which the use of energy generates

These first two activities aim to point out the social relevance of the problems that will be studied in the topic. These aspects increase students' interest and positive attitudes towards learning energy and physics (Solbes and Vilches 1997). In this way students are involved in the processes of solving different tasks.

Activity 8 Explain the transformations of energy which take place in the following processes: (1) A person firing an arrow upwards from a bow; (2) A water mill moving a dynamo by which a pump is supplied which introduces air into a balloon; (3) The water in a solar furnace which moves a turbine is heated by the sun's rays; (4) A nuclear bomb exploding.
In order to make the explanation easier, you should fill in the following table for each case:

Initial situation	Final situation
Description of the systems	Description of the systems
Energy description	Energy description

Chart for activity 8 that should be filled by students

The aim of the activity is to describe the changes which systems undergo and therefore the energy changes associated with the systems (objectives 1, 2, 4, Table 1). Students have to put into practice their knowledge of the different forms of energy (kinetic, gravitational potential, internal energy) and possible changes thereto in the transformation indicated in each situation (objectives 3–4, Table 1). For example, the explanation of the first situation will include a table as follows:

Initial situation	Final situation
Description of systems	
The arrow is in the archer's hands in the bow	The arrow is in the air at a certain speed and height
The archer has a certain constitution	The person's constitution has changed slightly
The air has a certain composition and temperature	The composition of the air has changed slightly and its temperature has gone up a little
Energy description	
The arrow has a lot of elastic potential energy but no kinetic energy	The arrow has no elastic potential energy and has acquired kinetic energy and gravitational potential energy
The archer and the air have a given internal energy	The archer has less internal energy
	The air has a little more internal energy

Chart for part of the solution to the activity 8

As explained, the conservation of energy does not provide a complete description without taking into account the degradation of energy (objective 6–7, Table 1). We present here one example of activity where work on these objectives is carried in the field of mechanics:

Activity 12 In the examples in activity 8 an "apparent loss of energy" occurs: The arrow finishes by falling to the ground and stops. Where is the energy given to the arrow? Can it still be used? We may apply similar reasoning to other situations, e.g. water heated by the sun goes cold in the end. Where is the energy which the water had before? Can we use it? Do any of these processes fail to comply with the law of energy conservation?

The groups of students, with the guidance of teacher, are able to establish hypotheses about the conservation of energy in the situations presented. For example, after the class discussion guided by the teacher, the final conclusion for the problem of the arrow is as follows: when the arrow hits the ground it finishes by stopping. Due to friction and entering the ground, both the arrow and the ground have increased their temperature and the structure of the ground has been deformed. In the end, there will also be an increase in the temperature of the air. Therefore, the energy will be in the form of internal energy in the arrow, the air and the ground. We may say that the energy has been conserved.

However, the students' explanation is not sufficient for answering the question: can the accumulated energy be used now? The teacher encourages the students to think about a situation which is very familiar to the students, such as the consumption of petrol in a car. The car moves but in the end stops in the garage, what has happened to the energy given up by the petrol? The students are capable of analysing the transfers of energy and establishing that the energy has not disappeared but has been transformed into internal energy in the air due to the increase in the surrounding temperature. However, they must be helped by the teacher to understand that this energy has ceased to be of use for work. The energy has been "degraded". It is not easy for the students to accept this concept and it is necessary to analyse different situations in order for the students to understand the difference between energy conservation and energy degradation.

The second example of activities is placed at the end of the sequence in the field of nuclear physics. The aim of the activity is to analyse the conservation of energy in the process of beta decay.

Activity 41 ¿What kinetic energy could we expect an electron issued during the beta disintegration of C-14 to have? However, the energy from the electrons may in fact assume any value between 0 and 0.16 MeV. It therefore looks like energy conservation is violated. ¿What other alternative solution may be proposed? (Data: C-14 mass: 14,00324 u; N-14 mass: 14,00307 u)

This is an activity which raises a historic problem which has caused new hypotheses to be put forward to preserve the principle of energy conservation. Faced with the problem, Bohr assumed that energy was not conserved during microscopic processes, but macroscopically. Faced with the prospect of having to abandon such well-founded principles as these, physicists opted for another solution. In 1930 Pauli assumed that during disintegration β, a new, hard to detect particle was issued apart from the electron, which Fermi later called a neutrino, thus completing $n \rightarrow p + e^{-} + \nu_e$. This new hypothesis gave rise to the prediction of a new atomic particle, the neutrino. In work with students it is not a question of them "rediscovering" the neutrino, but of them working on different explanatory hypotheses which can justify the principle of energy conservation. In fact, several groups of students suggested that there must be more particles in a nuclear reaction, although they did not manage to formally put forward a solution.

Experimental Design

The teaching sequence was implemented and evaluated for 2 years among students in the second level of high schools. The schools where the sequence was implemented were state schools situated in a medium-sized city. These types of schools are representative of the Spanish educational system. In the 2 year of implementation the participants were 131 students in the experimental groups (Group 1 $N = 57$, taught by one of the authors; Group 2 $N = 74$, taught by another author) and 168 students in the control groups. Both experimental and control groups followed the first level of the same high school introductory physics syllabus. In the second level the students were randomly distributed between the groups. The random distribution of students who have undergone the same previous programme of education is sufficient to ensure the same level of knowledge with the experimental groups.

Both the experimental and the control groups followed the same syllabus set by the government for all Spanish high schools. The instruction of energy last for 2–3 weeks. Work and energy, forms of energy, and energy conservation and degradation in different areas of physics are covered in lecture and homework. It includes three classroom hours and one laboratory or problem hour per week during the year. The control students used standard Spanish high school physics textbooks and did not normally have the opportunity to participate actively in lectures, being limited to taking notes of the teacher's explanations. These students complete weekly homework sets which mostly consist of standard quantitative end-of chapter problems. The experimental students attend the same syllabus and teaching timetable, but they complete the tasks of the designing sequence which involves qualitative conceptual-problems and standard quantitative problems. Experimental groups followed the teaching sequence and lectures focused on discussing the sequence's activities. The experimental students were involved in the teaching strategies described above.

In Spanish high schools, the number of female students is greater (59%) than the number of male students, but in physics the number of males is higher than the number of females (34%).

Evaluation of the Sequence

In order to answer the second research question the implementation of the teaching sequence was evaluated. We provide and discuss some quantitative (comparing large experimental and control groups) and qualitative elements, using analyses of tape-recorded interviews with students.

A questionnaire with eight items (see Tables 2, 3) was given to both the experimental and control groups about 2 months after the sequence. In respect of the validity of the contents of the questionnaire and its relevance to our goals, four members from the physics department of our high school, qualified and experienced in physics and teaching physics, completed the questionnaire and made suggestions that were taken into account when writing the final version of questionnaire. All faculty members confirmed that the contents of the questionnaire were appropriate for any student who had undertaken a physics course at a Spanish high school, regardless of the teaching strategies used in the course. In addition, a pilot study was conducted with small samples of students. This confirmed that, in general, students had no problem understanding the meaning of questions.

Table 2 Results obtained in the questionnaire by experimental and control groups

Number of question	Percentage of correct answers (%)				t-Value
	Group 1 ($N = 74$)	Group 2 ($N = 57$)	Group A[a] ($N = 131$)	Group C ($N = 168$)	
Q1. A tennis ball is dropped from rest onto a surface. After hitting the g round, it bounces and reaches a lower height than at first. Is the mechanical energy in the ball-ground system conserved?	74.3	84.2	78.6	4.6	219.0
Q2. When a body of mass 25 kg has been raised to a height of 300 m, it has a potential energy of 7,500 J. Where is that energy located?	55.0	66.7	60.1	2.7	148.3
Q3. An iron bar is made red-hot. Then it gets cold. Is energy conserved in the bar-air system?	67.1	75.0	70.5	33.1	83.8
Q4. Explain the transformations of energy that take place when electricity is generated in a damp environment and used to boil water	69.0	78.9	73.3	11.2	160.1

[a] Average of the experimental groups

Table 3 Results obtained in the questionnaire by experimental and control groups

Question number	Percentage of correct answers (%)				t-Value
	Group 1 ($N = 74$)	Group 2 ($N = 57$)	Group A[a] ($N = 131$)	Group C ($N = 168$)	
Q5. Newspapers often say there is a power crisis. How is this possible if you are told at school that energy is conserved?	64.4	75.4	69.2	13.1	139.2
Q6. Electro-magnetic waves emitted from a broadcast produce images and sound on your television. Explain this fact	73.1	78.2	75.3	13.1	157.3
Q7. When somebody shouts, the sound can only be heard up to a certain distance. Does this mean that the energy is not conserved?	73.2	75.0	73.9	45.5	64.1
Q8. According to Einstein, scientists say, matter can be converted into energy. Does this question the principle of the conservation of energy?	58.3	66.7	61.9	2.9	155.1

[a] Average for the experimental groups

In the second type of evaluation, the recorded interviews were analysed to assess the reasoning and arguments used by the student work teams when tackling problems. The students' discussions were transcribed verbatim into a protocol and they were analysed in the model for data interpretation proposed by Ericsson and Simon (1984). Interviews were carried out with 13 students from experimental groups. As a script for the interview we used the same items as the questionnaire.

Data Analysis

The analysis of the questionnaire is based on conventional comparison methods between the averages of answers considered as correct in both the experimental and control groups. To decide if there are significant differences, or not, between the experimental and control groups, the statistical parameter t is used for the habitual level of confidence of 5% or less (Crocker 1969).

We established criteria for correcting each question based on the objectives explained in Table 1. In Table 3 we present the first four question of the questionnaire. All questions (Q1, Q2, Q3, and Q4) aimed to find out whether the students knew how to apply their knowledge of energy concept to familiar academic situations. The questions are open-ended and focus on explanation rather than calculus and formula. The questions deal with the energy concept, its transmission, degradation and conservation.

In question Q1, a positive assessment means recognizing that energy is a property of a system that can transfer from one system to another (objective 1), and indicating that friction when hitting the ground causes part of the potential energy of the system to diminish and become transferred into internal ground energy (objectives 2, 4 and 6). Furthermore, the total energy of the ball-ground system is conserved (objective 5). In the same way, in question Q2, the criteria for a correct answer includes recognizing gravitational potential energy as energy due to the position of an object with respect to the earth (objectives 2 and 3). Question Q3 presented a phenomenon where energy transference through heat occurs. Answer which explain the cooling process of a body as a transference of energy taking as a system the body-environment group and therefore, confirming that energy is kept constant in the system (objectives

2, 6 and 8), were considered as correct answer. Question Q4 presented the different transformations of energy (potential, kinetic, electric potential energy) which occur in a hydro-electric station. Answers which explain the energy transformations which occur as well as the identification of work and heat as energy transference processes between systems were assessed positively (Objectives 2, 4 and 6).

We present the last four questions of the questionnaire in Table 3. In question Q5 the criteria for correct understanding involve using the following explanatory sequence: (1) the difference between sources of energy and forms of energy (objective 1 and 3); (2) analysis of energy degradation, i.e. its transformation into other forms of lower "quality" energy as they allow a lower number of transformation and can therefore be exploited less (objective 6); (3) application of the principle of energy conservation bearing in mind energy degradation (objectives 6, 7 and 8).

Questions Q6, Q7 y Q8 presented situations in areas other than mechanics and thermodynamics. The criteria for correct understanding and application mean applying explanatory sequences which take into account: (1) recognising the concept of energy in systems where electromagnetic fields (question Q6), waves (question Q7) or relativist (?; question Q8; objective 1 and 4) are present; (2) analysing the transference of energy in those systems, its degradation and the total energy conservation of the system (objectives 6 and 8). In question Q6 it is acknowledged that the electro-magnetic field contains energy, is transferred by means of waves or radiation and is transformed into other kinds of energy (luminic, mechanical kinetic energy). In Q7 the correct answer involves explaining that wave damping mechanisms (such as absorption) were assessed but indicating the total energy conservation in the wave-air system. In situations such as the one presented in question Q8, explanations which indicated that the mass/energy equivalence involves the principle of energy conservation were positively assessed, as energy at rest of the masses present was included.

Once the correction criteria had been discussed among the members of the research team, we held a training session in which we examined 10% of the sample. In order to classify the answers as "correct" or "incorrect", not only has the result been taken into account but also the explanation and argument used. Then we analysed all the questionnaires independently. The level of agreement among the reviewers when classifying the students' explanation as 'correct' or 'incorrect' answers was greater than 90% for each question. In the event of disagreement, the definitive classification was made by means of discussion and consensus between the reviewers.

In the second type of evaluation, the recorded conversations were analysed to assess the reasoning and arguments used by the students when tackling the items in the questionnaire. The students' discussions were literally transcribed into a protocol and they were analysed by using the answer categories for previous work on students' difficulties about energy conservation and degradation (Solbes and Tarín 1998). Throughout the analysis some variations were made to the previous categories according to the results obtained (Mortimer and Scott 2000). To complete the analysis of the recordings, we have also relied on analysing the written reports which each group had to produce at the end of the discussion. In short, we have tried to make the results of this qualitative approach to the students' reasoning as reliable as possible (Ericsson and Simon 1984).

Results

The principal aim of the teaching sequence was to evaluate its impact on students' understanding of energy conservation, transformation and degradation in different areas of physics. In order to answer the two specific question of the second research question we present the results in two sections.

Were Students Able to Analyse Energy Transference Processes and the Different Forms of Energy?

Table 2 collates the results of the comparative analysis of the answers given to questions 1, 2 and 3 by both the experimental methodology (group 1 and 2) and control groups (group C).

As we can see in Table 2, the differences between the average for the experimental groups and the control group are statistically significant for all items in accordance with the *t*-test at a level of confidence of $\alpha < 0.01$. A noticeable improvement can be seen specifically in the knowledge of energy transference processes (item 1 and 3). Also significant is the improvement in the understanding of forms of energy such as kinetic and potential energy (item 1 and 2).

As we mentioned in the "Data Analysis" section the inquiry into students' explanations do not only find 'correct' or 'incorrect' students' answer but also students' ways of reasoning and their conceptualization on energy concept, transference, conservation and degradation. The form of reasoning used by students can be seen in the explanations given by some students to the items in the interview. In the analysis of the interviews we established previous categories by taking into account findings from previous studies on students' difficulties and our objectives (Table 1). We can see in the following examples, the ways of reasoning of the majority of experimental students which were well assessed:

1. When analysing item 2, the majority of students recognized that energy is a magnitude of the system and not a property of a body.

(1) Interviewer	How does energy develop when a ball is thrown to the ground and goes on bouncing?
(2) Student	At first it has greater potential energy and as it goes on making contact with the ground, the force of friction causes the potential energy to diminish.
(3) Interviewer	Is there a transference of energy during the process?
(4) Student	The energy lost by the ball increases the internal energy of the ground. The system always has energy, if not potential energy, it has kinetic movement energy and if not, it is the internal energy of the ground.
(5) Interviewer	Are the energy which the system had at first and the energy in a bounce and that lost through friction the same?
(6) Student	They will be the same.
(7) Interviewer	Why?
(8) Student	The principle of energy conservation tells us that the total energy of the system, bearing in mind all forms, is the same.

The analysis of the reduction in the height of bounces of a ball thrown to the ground made by the student in the example was made by the vast majority of students when answering the questionnaire. They applied energy conservation and transference systems properly. In a significant number of replies transformation into internal energy, as shown in the example, was also quoted.

2. Nearly all the students interviewed explained the cooling process of a hot body as a transference of energy from the body to the environment, taking the group as a system and stating that all the energy is held constant in the system. Let's look at an example:

(1) Student	The hot body has more energy than cold
(2) Interviewer	So, why do you think that is?
(3) Student	Because you touch it and you get burnt
(4) Interviewer	If it then has less energy, where is that energy which it had at first and which it now no longer has?
(5) Student	The energy has disappeared. It has gone
(6) Interviewer	But, will it be somewhere?
(7) Student	Yes, it will be in the air
(8) Interviewer	How can energy pass from an iron bar into the air?
(9) Student	Because of the heat. It's the same as when you heat up water, the energy from the kitchen passes to the water through heating up the water
(10) Interviewer	Is the energy conserved?
(11) Student	Yes, because the energy lost by the iron bar passes into the air and, after all, it's the same

These results suggested that the students in the experimental group were able to use the concept of energy as a property of the system to apply the conservation of energy and moreover, to recognize the different forms of energy to analyse the process of transferring energy. The main difficulty experienced by students, as might be predicted by previous literature, involved differentiating between different forms of energy and the transference thereof. It is worth noting that, during 'standard' teaching in control groups, the teachers did make reference to the same physics phenomena and explanatory theories. However, this was not done in any interactive way, without involving activities and feedback.

To What Extent were Students Able to Use the Principle of Conservation of Energy in all Phenomena?

A summary of the percentage of correct answers by students to these questions is presented in Table 3.

Improvement in the correct understanding of the unified view of the principle of energy conservation influences an improvement in the knowledge relating to the identification of energy in areas of physics other than mechanics and thermodynamics. Another improvement aspect is the knowledge of how energy is transformed, degraded and conserved in wave phenomena (questions 6 and 7), which can be understood as the experimental group students correctly using energy analysis to apply the principle of energy conservation. The improvement in students' interpretation of energy conservation in the field of relativity (question 8) should be pointed out, although about 45% of experimental group students cannot be considered as having the level of knowledge set out in the objectives.

The form of reasoning used by students can be seen in the explanations given by some students to the items in the interview. With reference to energy degradation, nearly all the students interviewed correctly explained that it consists of transformation into other forms which are less usable. That is to say, they qualitatively referred to the second principle of thermodynamics without formally mentioning the concept of entropy. Let's look at an example of the transcription which can be considered as standard for all students:

1. A transcription of question 5:

(1) Student	It is possible for energy to be transformed into less usable energy. Because of this we say there is an energy crisis. Oil has internal energy which can be transformed into multiple forms of energy (kinetic, potential), but this is not the case with other sources
(2) Interviewer	But is the amount of energy conserved?
(3) Student	Yes. The amount of energy is always the same, but is transformed into other kinds of energy which are of less use to our society

The student differentiates between sources of energy (oil) and forms of energy which may be more "useful". He likewise reasons about energy degradation and the difference in conserving energy

2. A transcription of question 7:

(1) Student	Sound is transmitted by waves and these waves increase in size and are distributed over a greater area and are lost
(2) Interviewer	But is the amount of energy the same?
(3) Student	Yes, but it is divided into larger waves
(4) Interviewer	And why don't sound waves reach us?
(5) Student	Because there are other factors, air, friction, which cause them not to reach us
(6) Interviewer	But the energy in sound when leaving a person has a value (an intensity). And does that value diminish afterwards?
(7) Student	Yes, because the energy in the waves goes on transforming and passes into the air

The student explains attenuation and absorption as mechanisms for reducing the intensity of mechanical waves. The systems for defining the energy of a system, its transformation, degradation and conservation, explained in the teaching sequence seem useful tools to be used efficiently by students. Frequently, remembering elements from the sequence helps students overcome their difficulties in discussion and they are not blocked in the decision-making process.

Conclusions

Scientific theories are characterized by their great coherence and ability to predict phenomena in the natural world. These characteristics are widely accepted but usually it is not easy to pass this message on to physics students. Different factors often usually influence us teachers to present fragmented visions of physical theories. In this paper we have presented a design for a teaching sequence to show high school students the validity of energy conservation for any subject in the physics programme from classical mechanics to the special theory of relativity, via nuclear physics.

Regarding the first research question about how design helps students overcome students' difficulties in learning energy which are shown in science education research, we want to emphasise two aspects. The first deals with the context in which the teaching sequence was developed. We were restricted by the programme laid down in the Spanish high school curriculum and the challenge was to make changes to teaching strategies within these limitations. Due to these restrictions, it was necessary, to produce a very detailed teaching plan for the time available and show that students would not be disadvantaged when completing the more traditional types of problems commonly found in Spanish physics exams. In fact we proved that as well as being able tackle these new tasks effectively they were equally, or better, able to answer the type of questions typically used in physics courses in Spanish high schools (see Table 3).

From the point of view of teaching as classroom discussion, the second aspect deals with the problems of validating the sequence which cannot be disassociated from the problems of its design. The design and choice of the questions which the teacher proposes to students in order that they may progress in the investigation of task solving are fundamental. The development of prior detailed analysis in different dimensions (analysis of the concepts and laws involved, students' difficulties with learning and teaching support), designing subsequent questions which define specific learning situations and anticipating possible learning paths are basic elements in the design of open-ended tasks (e.g. see A.8 and A.12). Only sound design of questions-guide to problems makes it possible to assess specific teaching aims. Therefore, the description of possible teaching paths, the specific design of the sequence and validation of the aims of the teaching-learning process must be dealt with simultaneously.

Regarding the second research question, the present study has shown that the proposed teaching approach with its questions for guiding task solving, discussion activities, focus on relations between phenomena and explicative models yielded significantly better learning results in Table 1 than the traditional lecture/recitation approach. When working under the practical constraints under which this teaching was implemented, there is evidence that in questions related to energy conceptualization and its transference and forms of energy the majority of experimental students answered correctly and apply scientific types of reasoning (more than 60% in questions Q2, Q4, Q5 and Q6). Instead, less than 15% of control students reasoned in a scientific way in answering this kind of questions. On the other hand, three quarters of experimental students correctly applied the principle of conservation of energy and its degradation in question Q1 and Q3. Moreover, the majority of experimental students applied the principle of energy conservation in areas of physics other than mechanics and thermodynamics (Q7 and Q8).

However, this research has also indicated that strategies focused on 'formula without meaning' acquired by students during years of traditional teaching are difficult to change. A significant number of students (about 30%) solves tasks on the basis of a mechanical operativism and tries to identify the questions with one already known. This is, perhaps, more proof that in order for students to develop the abilities characteristic of scientific work it is necessary to put them into practice and to do so learning environments must be created in which students are asked to analyse evidence or data, compare the solutions given by different groups and justify the strategies used. A change in teaching strategies throughout the instruction stage and not just in one course is, therefore, necessary.

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