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Developing and Evaluating Research-Informed Instruction about Energy in Cyprus High Schools

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Also, I would like to thank my colleagues, physics teachers Constantia Cousouli and Savvas Demetriou for volunteering to participate in my research acting as the experimental and comparison group teachers.

ABSTRACT

There is an extensive academic literature documenting students' pre-instructional interpretations of phenomena and events, showing that these interpretations are not consistent with 'energy' as used in physics. Furthermore, there is evidence showing that teaching does not always result in students' interpretations becoming consistent with teaching. This evidence has been collected across many decades and in many countries.

This thesis presents a theoretical rationale for the design, implementation and evaluation of a teaching sequence aiming to promote conceptual understanding of the concept of energy to 15-16 years old physics students in Cyprus. Students' pre-instructional ideas about energy were investigated and were found to be consistent with those reported in the international literature. A design study was conducted with the aim of improving students' conceptual understanding compared to that might be expected from physics teaching usually conducted in Cyprus.

Among the perspectives and the methods critically reviewed to inform the design, the perspective set out by Leach and Scott (2002) drawing on the concept of Learning Demand was chosen. Furthermore, the energy ideas proposed within the SPT11-14 project (2006) were used as a basis for the development of the theoretical framework of the teaching sequence.

The research questions for the study were as follows:

RQ1.What concepts of energy are used by a Cypriot cohort of upper high school students prior to teaching?

RQ2. How do the conceptions and learning of the sub-cohort of Cypriot students taught through the research-informed approach compare with those following 'normal teaching' after instruction?

RQ3. How do the understandings of the energy concept, of a small sub-group of students, develop during the lessons of the research-informed approach?

The study involved thirty six Cypriot students in two classes of an urban upper secondary school. One of the classes acted as an intervention group, receiving the 'new' teaching sequence whilst the comparison group followed normal teaching.

For addressing RQ1, data were collected through a pre-test administered to all participant students. Pre-test data and data collected through a post-test also administered to all participant students were used to test the comparative effectiveness of the teaching, thereby addressing RQ2. To address RQ3, data collected from a small number of experimental students through pre and post-test, two short-length diagnostic probes, two interviews and through an interview conducted with the experimental teacher were used.

Analysis of data allowed for the following answers to each research question:

RQ1: The students' pre-instructional views about the concept of energy were not within the current scientific beliefs; rather, these were within an alternative context. They were consistent with findings reported internationally in the literature.

RQ2: The students' understandings of the concept of energy taught through the research-informed approach were significantly higher after instruction compared with those following 'normal teaching'.

RQ3: The students' understandings of the concept of energy through the lessons of the research-informed approach were developed in a manner consistent with the intended aims of the teaching.

The answers to the three research questions strongly suggest that the proposed teaching sequence for energy was found to be effective.

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In this introductory chapter, the orientation of the work conducted in this doctoral thesis as a design study is presented. The aims and the research questions of the study are stated.

Then, the perspective on energy taken in this study is defined, which is consistent with Feynman's abstract perspective.

This is followed by a brief presentation of energy within the context of international science education research. Research activity mainly followed two pathways: the investigation of students' accounts of energy; and the development and evaluation of approaches to teaching energy. Furthermore, the teaching of energy within a Cyprus education context takes place according to the 'forms' approach.

The focus is then turned on a brief presentation of the design of the research-informed teaching sequence for energy proposed in this doctoral thesis. The designing of the teaching approach drawn upon the research evidence-informed design for science instructional interventions, the learning demand design tool and the energy ideas proposed within the SPT11-14 project.

The chapter concludes with an overview of the doctoral thesis.

1.1 THE ORIENTATION OF THIS STUDY

This doctoral thesis presents a theoretical rationale for the design, implementation and evaluation of an innovative research-informed teaching sequence aimed at promoting conceptual understanding of the concept of energy to upper secondary school Cypriot students aged 15-16 years old.

The study carried out in this thesis is within the tradition of 'design research'. It sets out the design of a teaching intervention and also an evaluation of its implementation in terms of students' learning.

In setting up the design study, extensive research work found in the international science education literature reporting on the students' interpretations on phenomena and events prior to formal teaching was reviewed. The students' pre-instructional interpretations about energy reported in the international literature were compared with those of the Cypriot students and found to be consistent.

The international literature was searched for research work reporting on perspectives and methods to draw upon the design of the research-informed teaching sequence for energy and the design of the study. Among all insights gained by the critical review of perspectives and methods, the perspective set out by Leach, Scott and associates (Ametller, Leach and Scott, 2007; Leach and Scott, 2003; Scott, Leach, Hind and Lewis, 2006) was chosen. This informed design decisions at a fine grain size for both the content and the pedagogic strategies. Content-related decisions were informed by the Learning Demand design tool (Leach and Scott, 2002). In addition, the energy ideas proposed within the SPT11-14 project (2006) were used as a basis for the development of the theoretical framework of the teaching sequence. Furthermore, designing of the study included the testing of the relative effectiveness of the research-informed teaching sequence to promote conceptual understanding of the concept of energy compared to that might be expected teaching through the current Cyprus Curriculum for energy.

Therefore, the aims of the study were to:

- Review the international literature on teaching and learning about the concept of energy.
- Identify the key teaching and learning demands associated with the energy concept as described in the Cyprus National Curriculum for age 15-16 year.
- Develop a research-informed instructional sequence to address these teaching and learning demands.
- Implement and evaluate the instructional sequence.
- Review the overall strengths and weaknesses of the sequence including the views of the teacher.

The research questions for the study were as follows:

RQ1. What concepts of energy are used by a Cypriot cohort of upper high school students prior to teaching?

RQ2. How do the conceptions and learning of the sub-cohort of Cypriot students taught through the research-informed approach compare with those following 'normal teaching' after instruction?

RQ3. How do the understandings of the energy concept, of a small sub-group of students, develop during the lessons of the research-informed approach?

To address the first research question, data were collected with the use of a pre-test administered to students of both the experimental and the comparison group. Pre-test data and data collected through a post-test also administered to students of both groups, were used to test the relative effectiveness of the teaching and thus addressing the second research question. For the third research question, data was collected from a small number of intervention students through pre and post test, two short-length diagnostic probes and two interviews and from an interview with the experimental teacher.

1.2 THE CONCEPT OF ENERGY

Energy is perhaps the most fundamental of scientific concepts and currently holds a crucial role in the natural sciences, technology and wider society in coming to understand and control issues such as energy supply, the economics of transportation and nutrition.

The term 'energy' derives from the Greek word *ενέργεια* (energeia) which means 'action', 'activity', 'movement', 'operation' or 'work' (see, for example: Anagnostou, 2004, p. 402, Stamatakos, 1972, p. 338). Etymologically, *ενέργεια* is the abstract noun of the ancient compound adjective *ενεργός* (energos) the two components of which *εν+έργον* mean 'in work' (see, for example: Anagnostou, 2004, p. 402).

Energeia was used as a technical term for the first time by Aristotle in 4th century B.C. In his works Nicomachean Ethics I.viii1098b33 and Metaphysics VIII-IX energeia is discussed in the sense of activity or being at work. In various places of Eudemian Ethics II.i1218b and Nicomachean Ethics I.viii1098b33, he contrasts energeia with *δύναμις* (dynamis) which means 'force' or 'power' and *έξις* (hexis) in the sense of activity or operation. Furthermore, in Metaphysics IX.iii1047a energeia is compared to *κίνησις* (kinesis) which means 'movement' and sometimes has the sense of change (Peters, 1967, p. 55-56).

Despite its significance, energy is one of the most difficult and confusing of concepts, both to teach and to learn for deep understanding. One of the main reasons for these difficulties is that the word 'energy' is omnipresent in 'everyday language' and used in various ways which often are not consistent with, or even contradictory to, its scientific meaning (Solomon, 1983). As an example, energy in 'everyday language' is often associated with movement, force and activity, meanings which were attributed to it since the times of Aristotle.

A second main reason for attendant difficulties during the instruction and conceptual understanding of energy is its abstract nature; energy cannot be directly perceived or measured. Feynman, the famous Nobel Prize award-winning physicist admits that: 'It is important to realize that in physics today, we have no knowledge of what energy *is*' (Feynman, 1963, p. 4-2). In addition, due to its abstract nature, it would be fair to say that no simple and brief definition broadly accepted by scientists and science educators has been formulated so far. Pérez and Pujol (2007, p. 569) state that: 'Pedagogical practice shows that it is difficult to adopt a simple and direct definition like 'energy is …'.' and they suggest that: 'Rather, the concept of energy can not be presented and discussed out of its historical context. In order to understand really what energy is requires time: the concept is progressively grasped by observing that in every evolution of an isolated system an abstract quantity depending on the physical state of the studied system is conserved'.

1.3 THE PERSPECTIVE ON ENERGY TAKEN IN THIS STUDY

Physicist Richard Feynman, during a lecture to undergraduate students in 1961 at the California Institute of Technology, defined energy as follows:

> 'There is a fact, or if you wish, a *law*, governing all natural phenomena that are known to date. There is no known exception to this law-it is exact so far as we know. The law is called the *conservation of energy*. It states that there is a certain quantity, which we call energy, that does not change in the manifold changes which nature undergoes. That is a most abstract idea, because it is a mathematical principle; it says that there is a numerical quantity which does not change when something happens. It is not a description of a mechanism, or anything concrete; it is just a strange fact that we can calculate some number and when we finish watching nature go through her tricks and calculate the number again, it is the same' (Feynman, 1963, p.4-1).

Many physicists and physics educators agree with this view (see, for example: Warren, 1982), some others don't (see, for example: Falk and Herrmann, 1979, Schmidt, 1982); they defend the position of a substance-like nature of energy which can be stored in a system or flow from one part of a system to other(s) or from one system to another. Warren (1982) characterized the former view as the 'conceptualistic' (Warren, 1982, p. 295) view of energy whereas the latter as the 'materialistic' view of energy.

Nevertheless, the conceptualistic view of energy was formulated by Feynman fifty years ago. Since then, physics science has made many and great steps of progress and has gained insights in domains of modern physics such as quantum and particle physics. Within these domains, the classical, as it could be characterized, conceptualistic view of energy might no longer really valid; it might most probably undergone a fundamental revision. Furthermore, these perspectives are extended far beyond the borders of school physics and thus, they would be no further discussed. The view of energy taken in this study is consistent with Feynman's abstract perspective where conservation is the key property.

1.4 ENERGY IN THE CONTEXT OF SCIENCE EDUCATION RESEARCH

Energy as a scientific concept of crucial importance has attracted much interest within the science education research community over the past three decades and this focus remains until the present. Research activity has mainly followed two pathways: the investigation of students' accounts of energy; and the formulation and evaluation of teaching approaches aimed at the effective instruction of energy.

Studies following the first pathway have revealed a set of alternative interpretations that students of a wide range of ages and across various nationalities use prior to, and often after, the formal instruction of energy. For students, energy is conceptualized as: (a) something which is exclusively associated with animate objects, (b) a causal agent in specific objects, (c) something associated with force and movement, (d) a fuel, (e) a fluid, (g) an ingredient or, (f) a product (see Chapter 2 for a full account).

Furthermore, findings from pre-testing data analysis carried out in the study presented in this doctoral thesis, suggest that little progress has been made in the direction of energy education. Students tend to use the same alternative interpretations about energy as they did thirty years ago.

A review of the studies following the second research pathway (see Chapter 2) reveals that many attempts were made at the formulation of theoretical frameworks and the development of innovative teaching approaches to teach energy. However, a critical evaluation of these proposals has shown that these, in many cases, have failed in their main aim which is, to establish conceptual understanding of the concept of energy.

This failure in establishing conceptual understanding might be attributed to two main reasons. First, to the fact that some of them were based on a model of energy which is inconsistent with currently accepted scientific views for energy. One such example is the 'forms' of energy approach. Although there is evidence for the effectiveness of the approach, its theoretical framework includes considerable scientific inconsistencies (see Chapter 2).

The second reason is that other proposals were developed on scientifically consistent but difficult theoretical frameworks which made them inaccessible to many school students and thus inappropriate for school physics curricula. An example of such an intellectually challenging theoretical framework was proposed by Ogborn (1986) according to which, the occurrence of changes should not be attributed to energy but to entropy or free energy. As a process takes place in a physical system, energy is involved in the occurrence of a change whereas entropy or free energy is what decides whether or not the change will occur. The difficulty of this theoretical framework lies in the fact that it suggests the instruction of a difficult concept such as energy, through the use of an advanced physical law, that of the Second Law of Thermodynamics, with the pre-requisite of understanding an even more difficult and abstract concept, that of entropy or free energy.

Within the Cyprus Educational System, energy education starts at the sixth grade of primary school. It continues at the second grade of lower secondary school and then, at the first grade of upper secondary school. Furthermore, energy is taught in the advanced physics classes of second grade of the upper secondary school. As it is defined by the Cyprus National Curriculum for Physics, the instruction of energy takes place according to the 'forms' of energy approach. In particular, in the first grade of upper secondary school the traditional approach is followed; this includes the introduction of the concept of work and the mechanical forms of energy, the kinetic and the potential (gravitational and elastic) and the introduction of the energy conservation principle of mechanics. Moreover, emphasis is placed on the quantitative application of the conservation principle of mechanics in the analysis of energy problems.

1.5 THE DESIGN OF THE RESEARCH-INFORMED TEACHING SEQUENCE FOR ENERGY

The teaching sequence proposed in this doctoral thesis was developed according to research evidence-informed design of science instructional interventions (Scott, Leach, Hind and Lewis, 2006). Within this design, the development of the research-informed teaching sequence followed a four-step scheme as follows:

In the first step, the school energy knowledge to be taught was defined through the development of the theoretical framework of the teaching sequence. For this purpose, studies found in the international science education literature, reporting on approaches and theoretical frameworks aiming to teach the concept of energy were critically reviewed. Among all insights gained, the energy ideas proposed within the SPT11-14 project (2006) were selected as the basis on which the theoretical framework was developed. In the development process, the SPT energy model underwent considerable developments and innovations such as the elimination, modification and substitution of a series of elements proposed which were considered as sources of creating misconceptions, confusion or of difficulty in grasping the indented knowledge. Furthermore, the content of the current Cyprus energy curriculum was taken into consideration.

The second step included the consideration of how energy is conceptualized in the students' pre-instructional reasoning. A great number of studies found in the international literature, investigating the students' pre-instructional interpretations about energy were reviewed. Then, the Cypriot students' pre-instructional interpretations about energy were collected and compared with those reported in international literature were found to be consistent.

In the third step, the learning demands concerning the energy concept were identified. These were revealed by appraising the differences between the theoretical framework for energy set up in the first step and the Cypriot students' pre-instructional interpretations about energy considered in the second step.

In the fourth and last step, the teaching interventions addressing each of the learning demands revealed in the third step were designed and developed. This process included: the identification of the teaching goals addressing each specific energy idea, the development of a sequence of activities through the specific teaching goals be addressed, and, the specification of how these activities might be linked with appropriate classroom talk. A review of interactive teaching approaches reported in the international literature resulted in selecting the Communicative Approach (Mortimer and Scott, 2003). Then, each activity was linked with one of four classes of communicative approach which considered as appropriate to be used. Furthermore, the most of the activities included the use of computer simulations especially created to support the teaching goals addressed and all were supported by worksheets developed for each of these activities.

The research-informed teaching sequence was implemented with thirty six Cypriot students aged 15-16 years-old in two intact classes of an urban high school in Limassol, Cyprus. One of the classes acted as the experimental group, receiving the 'new' teaching sequence whilst the comparison group followed normal teaching. In this way, the innovative teaching sequence was evaluated on the grounds of its effectiveness in establishing conceptual understanding, in comparison with normal teaching. Findings of data analysis strongly point towards the relative effectiveness of the instructional sequence.

1.6 OVERVIEW OF THE DOCTORAL THESIS

As stated in section 1.1, the study carried out in this doctoral thesis is within the 'design and evaluation' tradition. This line of work is explicitly mirrored in the flowchart of the chapters included in this doctoral thesis presented in Figure 1.1.

Chapter 1: Introduction

It sets out the orientation of the doctoral thesis as a design study and a brief description of the work done following this scheme.

Chapter 2: Literature Review

It sets out the literature on students' interpretations of phenomena and events were scientific interpretation draws upon energy, plus literature on approaches to teaching energy.

Chapter 3: Research methodology

It sets out the conceptualisation of the whole study, plus methodological decisions about evaluation.

Chapter 4: The design of the teaching sequence: Methodological basis and practical decisions

It sets out the rationale for the design, and accounts for actual design decisions in the teaching intervention.

Chapter 5: Evaluation of the teaching-Findings for RQ1 and RQ2

It sets out an evaluation of the implementation of the research-informed teaching sequence. This continues in the next Chapter 6.

Chapter 6: Evaluation of the teaching- Findings for RQ3

The evaluation of the implementation of the research-informed teaching sequence continues following that carried out in Chapter 5 and concludes.

Chapter 7: Summary of the findings and discussion

It sets out a summary of the design and evaluation work done, a methodological critique, discussion on the implications of the study on energy education, both in a Cyprus and an international context and finally, recommendations for further study are formulated.

Figure 1.1: Overview of the doctoral thesis.

CHAPTER 2-LITERATURE REVIEW

This chapter presents a review of extensive academic work concerning energy found in the international science education literature.

In the first part, studies reporting on the students' alternative interpretations about energy are reviewed. These were conducted across a few decades and in many nationalities.

In the second part, studies reporting on theoretical frameworks and approaches for teaching energy are reviewed and critically discussed.

2.0 INTRODUCTION

Energy as one of fundamental scientific concepts included in science education curricula has been the subject of extensive research studies. The studies carried out have mainly focused on the investigation of the students' alternative interpretations of phenomena and events where scientific interpretation draws upon energy and on the formulation and development of innovative teaching approaches aimed at the effective instruction of energy.

In this chapter, the international science education literature concerning energy is reviewed. First, studies reporting on the students' alternative interpretations about energy are considered. Discussion is then turned to a critical review of studies reporting on proposals for teaching and learning the energy concept.

I. THE STUDENTS ALTERNATIVE INTERPRETATIONS ABOUT ENERGY

Results from research on primary, secondary and university students and even pre-service teachers' understandings of energy revealed a set of alternative interpretations and difficulties prior and even after instruction. Gilbert and Pope (1986) categorized alternative interpretations about energy into the following conceptual models: *(a) anthropocentric*, *(b) depository*, *(c) activity*, *(d) functional*, *(e) flow-transfer*, *(f) ingredient* and *(g) product.*

In the following sections, each of seven alternative models are presented and discussed.

2.1 Energy and animate objects-The Anthropocentric Model

Several studies undertaken with a range of students of all age levels revealed that energy is associated with animate objects and in particular with human beings. Watts and Gilbert (1985) identified a 'human centered' framework for energy according to which energy is associated mainly with humans or with objects to which they attributed human characteristics. Black and Solomon (1983) reported a shift away from 'living associations' of energy with age. In a study with students aged 11-13 years, they found that while the notion was prevalent among youngest students, many students began to expand their perceptions of energy into a more general conceptual framework in which 'non-living' associations such as electricity, power stations, moving objects, lighting and fire were included. Furthermore, Solomon (1983) noted that girls associate energy with animate objects in a greater proportion than boys.

Solomon (1983), in studying students' responses classified them into four themes two of which relate to the anthropocentric model. These are:

- *vitalism*, a notion which has its origin in eighteenth century according to which energy is considered as something indispensable for life;
- *activity*, according to which humans need energy to move.

In a study carried out by Stead (1980), students expressed views on energy within the notions of vitalism and activity. Moreover, they expressed the notion that energy is related to fitness and strength stating that without energy human beings would be tired, unfit or listless. In addition, they considered that non-living objects do not need energy.

Human-centered views about energy are not expressed only by students but also by adults. In a study conducted by Kruger (1990) aimed at the investigation of pre-service primary teachers' views on energy it revealed that many of them had the notions of vitalism and activity.

2.2 Energy as a source of activity-The Depository Model

According to the depository model, certain objects, materials or devices such as fuels, food and batteries can deposit or re-deposit energy, need energy or expend the energy they get. Energy is considered as a causal agent which is stored in certain objects

(Gilbert and Pope, 1982; Trumper, 1990a; Watts and Gilbert, 1985). In a study conducted by Solomon (1983) it was found that some students related energy with machines, or some kinds of work to an input of energy coming from electricity or another 'kind' of fuel. Ault et al. (1988) also report a framework in which some objects are thought by students as sources of energy in which it is stored.

The depository model was also identified by Kruger (1990) in a study with pre-service primary teachers. In their responses, the teachers seemed to consider energy as a 'hidden force' which remains as such waiting to be used.

2.3 Energy, movement and force-The Activity Model

Within the activity model, energy is associated with movement, force and activity. Stead (1980) found that students who associated energy with movement considered that there is energy only in inanimate moving objects whereas in the case of non-moving objects, that they could not have energy. Watts and Gilbert (1983) reported similar findings and added that in many cases, the movement itself was perceived as energy. Gilbert and Pope (1982) in their turn reported that movement was often considered as a way for energy to be expressed. Watts (1983b) also identified a similar framework for energy within which energy is associated with obvious activity with movement being specified as the reason for energy being involved. Furthermore, the association between energy and movement was also reported by Solomon (1983a).

In studying students' responses aged 12-13 years, Duit (1981) found that energy and force were closely associated whilst Brook and Driver (1984) identified a close association between energy, force and movement in the students' perceptions. A study undertaken by Watts and Gilbert (1983) revealed that the concepts 'energy' and 'force' were used as synonymous by many students whereas other students, although they could distinguish between them, used them as interconnected concepts. Similar findings were reported by Orfanidou (2007) in a study with first year primary education university students. Gilbert and Pope (1982) and Stead (1980) also reported the use of energy as synonymous with force and moreover, confusion between energy, force, friction, work and gravity. Furthermore, Ault et al. (1988) identified confusion between energy and work, force and power whereas Barbetta et al. (1984) suggest that confusion between these concepts is not only terminological but also conceptual. Confusion between energy and power was also noted by Goldring and Osborne (1994).

The notions that there is no energy in non-moving objects and that energy is associated with movement and activity was also identified by Kruger (1990) in a study with pre-service primary teachers. Some teachers expressed the view that the amount of kinetic energy of a moving object does not depend on its speed whereas other teachers perceived friction and gravity as energy. Finally, it was revealed that many teachers seemed to confuse 'energy' with 'force' while some others used the two concepts as synonymous.

2.4 ENERGY AS A FUEL-THE FUNCTIONAL MODEL

The notion of energy as a fuel, the resources of which are limited, seems to be prevalent among students worldwide. Solomon (1983a) found that one of the students' most common responses related to shortage of energy in the future and the need for new energy sources to be found in order for the needs of the planet to be satisfied. The researcher classified these responses in an individual category which she named 'energy shortage'. Duit (1981) also identified the use of 'energy crisis' in some students' responses whereas a considerable number associated energy with power plants. In a later study with students from Germany and Philippines in grades 7-10, Duit (1984) found that in German students' responses energy was closely associated with fuels and electricity; however, associations of this kind were not identified in Philippine students' responses. Furthermore, Ault et al. (1988) also noted a similar view for energy considered as a fuel.

A study carried out by Stead (1980) revealed that many students used in their responses the word 'energy' as synonymous with the word 'fuel'. Furthermore, as the researcher remarks, the use in everyday language of the phrases 'energy crisis' and 'conserve energy' which actually mean 'fuel crisis' and 'fuel conservation' led the students to the belief that fuel is energy.

Watts (1983a) identified 'functional' energy as another framework for energy according to which, energy is considered as a general kind of fuel. Within the functional framework, energy is mainly associated with its applications; it is considered by students as something necessary for things to work, specifically by technical appliances, and associated with processes which make human life comfortable.

Another view expressed by some pre-service primary students in a study carried out by Kruger (1990) was that energy comes from the sun.

2.5 Energy as a fluid, an ingredient or a product- The Flow-transfer, Ingredient and Product Models

Three further models are identified by Watts and Gilbert (1985), that of energy as a fluid, an ingredient or a 'by-product'.

According to the 'flow transfer' framework, energy is considered as a fluid which can be 'put in', 'given', 'transported' or 'flow' from one object to another. The notion of energy as a fluid is also reported by Duit (1981) and Gayford (1986) and by Orfanidou (2007) in a later study with first year primary education university students. As Orfanidou (2007) noted, a frequent notion in the students' interpretations was that energy can be 'released' from one part of a system and flow to another part or parts of it. Furthermore, the idea of energy as a substance in nature quantity was reported and by Stead (1980).

Within the 'ingredient' framework, energy is associated with fluids or ingredients and is considered as a reactive rather than a causal agent which remains dormant in them until it is released suddenly by a trigger. Furthermore, energy is considered to arise all of a sudden as a result of a kind of combination of ingredients.

Turning to the 'product' framework, energy is viewed as a 'by-product' of a situation, as a relatively short-lived product which is generated, is active and then disappears or fades.

2.6 Conservation of energy

The conservation of energy is a fundamental idea related to the nature of the concept of energy. However, research suggests that in fact, only a few students have a scientific understanding of the idea (Boyes and Stanistreet, 1990). Boyes and Stanistreet (1990) carried out a study with 1130 students aged between 11 and 16 year, aimed to determine the degree to which students' appreciation of the law of conservation differs in different age groups. Findings revealed a low percentage of students in the 11-12 year old group identifying an acceptable meaning of the law of conservation of energy and furthermore that even in the 15-16 year old group only one third of the students were certain of this response.

Duit (1981) reports that a study which he conducted with students aged 12-14 years revealed that they do not see a need for the idea of conservation. In explaining their responses, none of the students made use of energy conservation before instruction whereas after instruction, only a few mentioned it. Furthermore, the students tended to explain in terms of observable features of the system under study. As Duit suggests, students prefer to use ideas gained from everyday experience rather than scientific ideas such as energy, taught in science lessons.

The findings reported by Driver and Warrington (1985) supported those of Duit. A study which they carried out with students aged 13-18 years, all of whom had been exposed to energy conservation instruction, revealed that only a few students used interpretations in terms of energy conservation in their responses. Moreover, the researchers found that although the students were able to use energy conservation, they tended to give interpretations using some more conceptually obvious ideas rather than the energy conservation given a free choice.

Brook and Driver (1984) also reported that only a few students made use of the conservation of energy idea. In addition, they found that many students preferred to focus on tangible features of the system under study instead of using energy ideas, even when they were explicitly directed to do so.

Black and Solomon (1983) found that students encounter considerable difficulty in integrating the scientific idea of conservation of energy with their everyday experience. They suggest that this difficulty might be attributed to the contradictory way the scientific words 'energy' and 'conservation' are used in everyday language. Furthermore, they report that when the students were asked to describe fully in terms of energy the bouncing of a ball, some students, although they recognized the conservation of energy principle, intuitively stated that energy could be lost. In addition, only a few students used the energy conservation idea whereas a considerable number stated that since energy cannot be destroyed, it must be stored in some way, or that it must turn up again in its original form.

Ault et al. (1988) noted that the 'energy gets used up' view according to which things go until energy is used up or fuel is consumed appears frequently in the students' responses. In their turn, Goldring and Osborn (1994) report that in many students' responses, the notion that 'conservation of energy' actually means 'save energy' was included whereas others expressed the view that energy is conservable only within a laboratory.

Difficulties concerning the conservation of energy idea were also identified among university students and prospective science educators. For example, Liu et al. (2002) reported that university chemical engineering students failed to use the conservation of energy principle in interpreting the temperature change in solution processes.

In a study with first year primary education university students, Orfanidou (2007) found that only a negligible number used energy conservation in their interpretations prior to instruction. The students were asked to describe fully the changes observed in a system in which a football player was shown to kick a ball and set it in a decelerated motion on a horizontal plane and finally stop at a small distance. Half of the students stated that at the end, the energy of the system is stored in the same amount and form, in the place or places in which it was initially stored. According to the researcher, this view suggests little understanding of the conservation of energy idea. As discussed earlier, similar findings were reported also by Black and Solomon (1983). Moreover, a considerable number of students expressed the view that energy is not conserved through expressions such as 'energy disappears' or 'energy stops to exist' in their interpretations.

A study carried out by Kruger (1990) with pre-service primary teachers revealed that many of them considered energy as a non-conservable quantity.

2.7 Other alternative interpretations about energy

Further research revealed additional alternative interpretations which are not classified in any of the models for energy presented earlier. These are presented in the following.

- whenever there is an energy transfer, mechanical working is done;
- mechanical working 'produces' force and;
- there is heating whenever mechanical working is done.

In a study carried out with university students, Orfanidou (2007) identified student ideas that:

- 'pressure' is stored in a compressed spring;
- mechanical working done by the weight of an object (or the force exerted by a worker on an object) is proportional to the effort made by the worker when lifting up the object;
- mechanical working done by the weight of an object (or by another force exerted on the object), during its movement from one vertical position to another, depends on the path followed by the object between the two positions;
- the amount of energy in a gravitational store of the system object-Earth is proportional to the effort made by a worker when lifting up the object;
- the amount of energy in a gravitational store of the system object-Earth depends on the path followed by the object when moving from its initial to its final vertical position;
- energy is stored only in a gravitational store of the system object-Earth during the vertical movement of an object.

Furthermore, Kruger (1994) identified what he refers to as a 'theocratic view' of energy among pre-service science teachers. A few teachers used metaphysical interpretations in their responses according to which, energy comes from God.

II. PERSPECTIVES ON THE ENERGY CONCEPT AND APPROACHES TO THE TEACHING AND LEARNING OF ENERGY.

In this section, various proposals for teaching and learning of the concept of energy and the discussion conducted about their effectiveness among researchers are presented and critically discussed.

2.8 ENERGY IS THE ABILITY OF DOING WORK

Warren in a series of articles (1982, 1983, 1986, 1991) argues for a conceptual view of energy within the context of school physics. According to Warren:

> 'In science there is a mathematical abstraction, called energy, which is the capacity of a body or system for doing work (in the scientific meaning of the word) by ideal processes. Different kinds of energy are defined in terms of the properties of systems which would enable them to do work directly or indirectly in some ideal way'(Warren, 1991, p. 8).

and

> '... its importance lies in the fact that for all phenomena hitherto studied thoroughly a rigorous law of conservation is found to be applicable' (Warren, 1982, p. 295).

Elsewhere he states that:

> 'Energy is an abstraction used in theoretical analysis of phenomena, and is not a commodity, a phenomenon or a sensation. The only way in which one can have 'experience' of energy is by using the concept in an analysis or calculation' (Warren, 1983, p. 210).

In expanding his reasoning, he describes a few examples one of which is the following (Warren, 1983, p. 210):

> 'When a body of mass *m* is raised through a distance *x* above the ground it is said to have acquired a potential energy mgx. According to current teaching methods this energy is a 'substance' which has been put into the body. Actually nothing has been put into the body, which is unchanged except in position. If it is allowed to return to the ground *the gravitational field of the earth* will do work on it equal to *mgx*. That is, potential energy is not something in the body. It is an abstract quantity, the calculation of which helps us to predict what will happen when the body returns to the ground'.

Warren makes a distinction between the concept of energy and the concept of work; he stresses that energy is 'a quantitative measure of the *condition* of a system whilst work is a *process*. Energy may be transformed or transmitted (or both) by *means* of work, but it cannot be transformed into it' (Warren, 1982, p. 296). In explaining the distinction that he makes between energy and work, he gives the following example:

> 'For example we should be clear that a domestic electric meter measures the work done by the generating station upon household appliances; it does not measure the energy of anything ...' (Warren, 1983, p. 210).

He also distinguishes between heat and work. He claims that heat and work, are both processes of energy transfer; their difference lies in the fact that in an energy transfer with work macroscopic movements and interactions are involved whereas in the case of an energy transfer with heat work is done on a microscopic scale (Warren, 1982).

The theoretical framework for energy formulated by Warren is indeed a conceptual one since firstly, it coincides in its main points with the scientific meaning of energy expressed by Feynman and secondly because work, like energy, is an abstract physical concept. However, the definition of energy as 'the ability to do work' resulted in much criticism (see, for example: Duit, 1981, Hicks, 1983, Lehrman, 1973, 1982, Sexl, 1981,Trumper, 1990) since it was dominant in secondary and college textbooks, even before Warren published any of his work, resulting in a strong debate concerning its scientific validity.

The first among science education researchers who rejected in an article the definition for energy as the ability (or capacity) to do work was Lehrman (1973), after the examination of twelve high school textbooks in eight of which it was included. As he points out, he rejects the definition because of three errors in it:

> '1. It is so barren of content that it seems to be designed for ease of memorization rather than promotion of understanding.
> 2. It grossly distorts the nature of the important social problem of availability of sources of energy.
> 3. It is not true' (Lehrman, 1973, p. 15).

In a further discussion about the scientific consistency of the definition, Lehrman argues that the definition is false due to the fact that energy is conserved whereas the ability of doing work is not. Concluding, Lehrman states that: 'A modern definition of energy, then, must be based on both the first and second laws of thermodynamics. Anything less falsifies the picture. If it is not possible to write a satisfactory definition in a few words, we will have to learn to get along without any such neat package' (Lehrman, 1973, p. 18).

In a later article, in which errors in high school textbooks were examined, Lehrman expresses a similar point of view about the definition:

> 'It is time to dump this hoary chestnut, as it implies that it is not possible for both the first and second laws of thermodynamics to be true. The first law tell us that the total amount of energy does not change, and the second law insists that the amount available to do work always diminishes' (Lehrman, 1982, p. 520).

Another researcher who expressed his disagreement about defining energy as the ability of doing work is Sexl (1981). He claims that energy is among those physical concepts which cannot de defined with an operational definition. Furthermore, he adds that: 'The question 'what is energy?' has no simple answer. The statement that 'energy describes the capacity of a system to perform work' is not satisfactory...' and he justifies his point of view claiming that: '... since it cannot be used in thermodynamics. There the internal energy of a system cannot be transformed completely into work' (Sexl, 1981, p. 286).

Starting from Sexl's point of view that it is not possible to introduce the concept of energy in school physics using an operational definition and much more to define energy as the ability to do work, Duit (1981) also raises objections and adds that this should not be used even if the purpose is to provide students with an initial semantic description. In a later article, Duit (1985) investigates the definition in more detail. He states that the definition: '... bases the energy concept on mechanics' (Duit, 1985, p. 72) since the general concept of energy could be defined starting from its definition in mechanics. However, he rejects the claim that the definition acts for the concept of energy as a 'restriction to mechanics' (Duit, 1985, p. 72). He expresses the point of view that (Duit, 1985, p. 72): 'This is a view which cannot be supported in physics. It is quite possible to define step by step a general energy concept by building on the energy concept of mechanics'. He adds that the 'restriction to mechanics' claim is true in the sense that: 'Often the definition simply acts as a brief paraphrase of the term 'energy'' (Duit, 1985, p. 72). That results in retaining the definition by the students even when the concept is introduced in areas of physics other than mechanics.

Among those positioned against the definition is also Hicks (1983). In expressing her objection she states that: 'However, as every physicist well knows, it is not true. It is a direct contradiction of the laws of thermodynamics' (Hicks, 1983, p. 529). Furthermore, she remarks that (Hicks, 1983, p. 530): 'The general concept of energy is very difficult to define' and as far as it concerns the definition she points out that it would be better: '... to give up the simple but incorrect definition of energy as the capacity to do work. It probably should not be used even as an initial definition even with remarks about its inadequacy, because it is so memorable that it may retained by a student long after all caveats have been forgotten' and proposes: '... to avoid any simple definition of energy'.

In replying to criticisms and all objections raised concerning the contradiction between the definition and the Second Law of Thermodynamics, Warren defends the definition claiming that:

> 'This objection appears to be based upon a misunderstanding of the second law of thermodynamics. This law expresses restrictions on what can be done in cyclic processes, it does not exclude the possibility of a body doing more work in other circumstances than it can do when it is part of a continually operating heat engine-consider the expansion of compressed air. We do not deny that the Matterhorn has gravitational potential energy because it is impracticable to lower it to sea-level. It is very unfortunate that there should

be any impression that the traditional concept energy is inapplicable in thermodynamics' (Warrren, 1982, p. 296).

Furthermore, in a letter published in Physics Education (Warren, 1991) he further expands his argumentation about the correctness of his definition of energy. In the same volume, Bamford (1991) also defends the definition using a similar argument used in Warrens' letter.

The scientific consistency of the definition was also advocated by Duit (1985) by giving a similar and more explicit scientific justification to Warren's and Bamford's. He attributed the raised objections to superficial examination of the definition. Furthermore, he pointed out that objections should be taken into consideration since very precise knowledge of the subject matter of physics is needed in order for the definition not to be considered as in contradiction to the Second Law of Thermodynamics.

2.8.1 DISCUSSION

The definition 'Energy is the ability (or capacity) of doing work' eventually became less popular in high school and college physics textbooks. For example, this was eliminated from physics textbooks in Cyprus more than a decade ago. The key point of all debate concerns, in my opinion, its instructional value and usefulness as an instructional tool rather than its consistency with the Second Law of Thermodynamics. The previous discussion indicates that the conceptualistic approach which Warren proposes for the instruction of the concept of energy gives rise to various problems. One of the main problems relates to the appropriate time of introducing energy in school physics. As Warren (1982, 1986) points out, the instruction of energy with the use of the work definition prerequisites an understanding of the abstract concept of work and in turn, an understanding of other difficult physical concepts such as force and displacement as well as an ability in mathematical treatment. Within this scientific context, the instruction of the concept of energy is confined to upper grades in which students have already acquired the ability of abstract thinking and advanced mathematical skills. Furthermore, he suggests that the instruction of energy should be addressed to older students, after the age of 16. However, as discussed in Chapter 1, energy is one of fundamental scientific concepts with a key role in coming to understand socioeconomic issues. Moreover, the importance in acquiring understanding, not only by scientists but also by all citizens, of fundamental concepts such as energy was pointed out by Hobson (2003). As he remarks, there is a need for all citizens, especially those who live in industrialized democracies, to be scientific literate. This results from the fact that many of the most crucial decisions concerning science and technology are made by citizens.

All previous discussion advocates an early introduction of the concept of energy. Thus, it is my view that if one of the instructional goals is to help students to acquire an understanding of energy which may be useful to them as future citizens, then the concept should be introduced early and much before the age of 16, as Warren suggests. After the age of 16, a proportion of the students do not attend high school and many follow higher education studies in subjects other than science and technology.

Another problem in the instruction of the concept of energy, due to the use of the work definition, was already pointed out by Duit (1981, 1985); that is, there is a risk of the definition being used by the students as 'a brief paraphrase of the term 'energy'' (Duit, 1985, p. 72) and retained when introducing the concept of energy in areas of physics other than mechanics within which it is mainly well established. This again, dictates the need for using an approach in which the introduction of the concept of energy will not be based on the concept of work. Rather, the teaching approach should be based on the unifying character of energy.

2.9 ENERGY AS A QUASI-MATERIAL

Schmid (1982) reported on an innovative physics curriculum which was developed at the Karlsruhe Institute for the Didactics of Physics by Falk and Herrmann (1977, 1978, 1979, 1981) to cover all educational levels, beginning at elementary level at the ages of 10-12 years through university level. This aimed at the restructuring of physics on a completely different epistemological perspective within which physical quantities are introduced in a more pictorial way, as substance-like quantities (Schmid, 1982, p. 212). A substance-like quantity is defined as '... any physical quantity for which a density can be defined, i.e. any quantity which can be thought to be distributed in the flow through space. Accordingly, it makes sense to ask whether or not each obeys a conservation equation' (Schmid, 1982, p. 212). Substance-like quantities include energy, entropy, momentum, angular momentum, electric charge, mass, amount of substance (number of particles) and others. On the other hand, intensity quantities include temperature, speed, angular velocity, electrical potential and others.

In a succeeding article, Falk, Herrmann and Schmid (1983) presented the substance-like nature in more detail stating that:

> 'The substance-like nature of energy follows from the fact that a density and a current exist for the energy (the energy current is traditionally called 'power'). It is also evident in the fact that it makes sense to ask about the local conservation of energy. Indeed, energy is a conserved, substance-like quantity' (Falk, Herrmann and Schmid, 1983, p. 1074).

Within this epistemological perspective, energy is introduced as a primary quantity, namely, a quantity which does not derive from other fundamental physical quantities as for example in the definition 'energy is the ability of doing work', where energy derives from the physical quantities 'force' and 'displacement'. Energy, as stated earlier, is considered as a substance-like quantity, which can be stored in a system and flow in a particular form from one system to another. Every energy form is characterized by both an intensity quantity and a substance-like quantity. For example, in the case of heat, entropy corresponds to the substance-like quantity and temperature to the intensity quantity respectively.

Schmid (1982) claims that the understanding of the main features of various processes evolving in physical systems can be based on the idea of the flow of energy. He states that this could be expressed more completely in terms of the following rule: 'Something is happening whenever energy is flowing and a flow of energy is always accompanied by the flow of at least one other substance-like quantity' (Schmid, 1982, p. 212). Furthermore, he explicitly states that the substance-like quantity which accompanies the flow of energy 'carries' the energy and thus, the term energy *carrier* could be used (Schmid, 1982, p. 212). In addition, the intensity quantities are considered as a measure of the amount of energy 'carried' by the energy carriers.

Expanding the Karlsruhe theoretical framework, Schmid states that the flow of energy carriers takes place along channels. The device from where the energy carriers begin is called an *energy source* whereas the device to which it ends an *energy receiver*. In clarifying these new elements, he describes several examples of the flow of energy carriers from an energy source to an energy receiver. In the following, one of these examples is presented: 'For example, a car engine receives energy with the carrier petrol. In this case, the petrol tank is the energy source. The energy carrier channel is the fuel line (Schmid, 1982, p. 213).

The flow of an energy carrier current from the energy source to the energy receiver can be represented symbolically by an *energy flow diagram* (Schmid, 1982, p. 213). In Figure 2.1, various energy flow diagrams, which correspond to everyday processes, are illustrated (Schmid, 1982, p. 213).

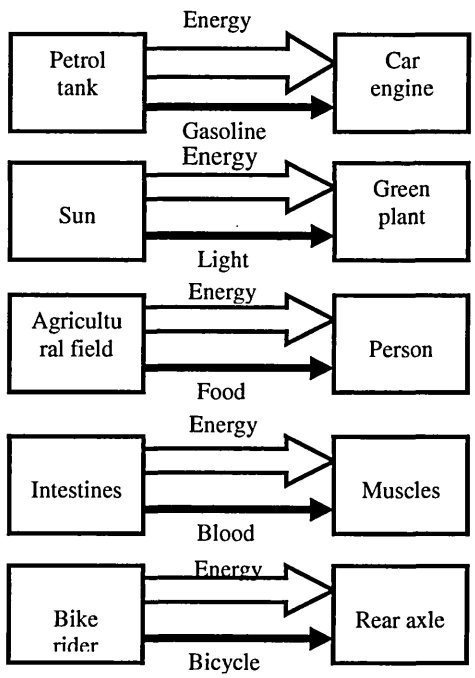


Figure 2.1: Energy flow diagrams representing everyday processes.

The energy carriers are categorized, according to their function, into *return* and *nonreturn energy carriers* (Schmid, 1982, p. 213). In order to define the two kinds of energy carriers, Schmid states that: 'Unless it is stored within the energy receiver, the energy carrier does not just disappear within the receiver. Rather, the energy carrier unloads its energy within the energy receiver and then goes further, either to be simply 'thrown away' like a nonreturnable soda bottle or to be returned to the source like a returnable bottle' (Schmid, 1982, p. 213).

As far as it concerns the nonreturnable energy carrier, Schmid gives as an example the air which carries energy between a compressor and a hydraulic motor.

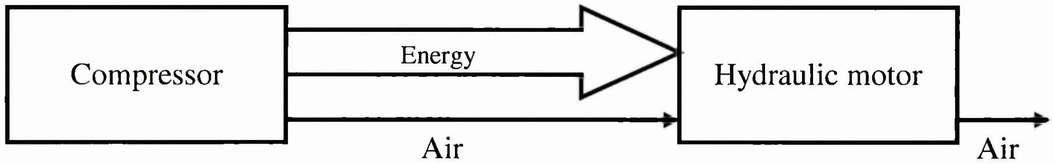


Figure 2.2: An example of a system with a nonreturnable energy carrier.

In the example illustrated in the above Figure 2.2, the energy carrier, air, 'loads' with energy at the energy source, the compressor, then it 'unloads' the energy at the energy receiver, the hydraulic motor and finally, it is 'thrown away'.

For a returnable energy carrier, he uses as an example the water which circulates between the boiler and the radiator of a central heating system (Figure 2.3):

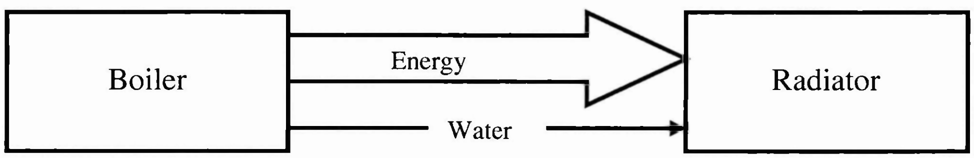


Figure 2.3: An example of a system with a returnable energy carrier.

In the example illustrated in Figure 2.3, the energy carrier, water, loads with energy at the energy source, the boiler, then it 'unloads' the energy at the energy receiver, the radiator and finally, it returns unaltered to the energy source, the boiler, to be 'reloaded'.

Nonreturnable energy carriers flow, as it may be assumed from the example illustrated in Figure 2.3, in only one channel which begins at the energy source and ends at the energy receiver. On the other hand, the return carriers flow in two channels, that is, firstly through the channel energy source-energy receiver where they 'leave' the energy they 'carry' to the energy receiver and then, without being altered, through the channel energy receiver- energy source where they are 'reloaded' with energy. Schmid points out that the same carrier can be loaded with different amount of energy. In clarifying this statement, he gives the following example: 'For example, consider heating a room with a hot water radiator. The water entering the radiator is obviously at a higher temperature than the water leaving it. On the other hand, we know that a radiator transfers energy from the water entering the radiator to the energy carrier air. Thus, the water at the higher temperature carries more energy than the water at the lower temperature' (Schmid, 1982, p. 213).

Schmid presents another key element included in the Karlsruhe theoretical framework, that of a *transceiver* (Schmid, 1982, p. 214). A transceiver is defined as a device which can function both as an energy source and as an energy receiver; that is, in the case of successive processes, the energy receiver of the preceding process becomes the energy source for the following process from which, energy is carried by one or more energy carriers to a new energy receiver.

A transceiver is represented as a single block diagram with arrows entering and leaving it. Figure 2.4 (Schmid, 1982, p. 214) illustrates a chain of transceivers.

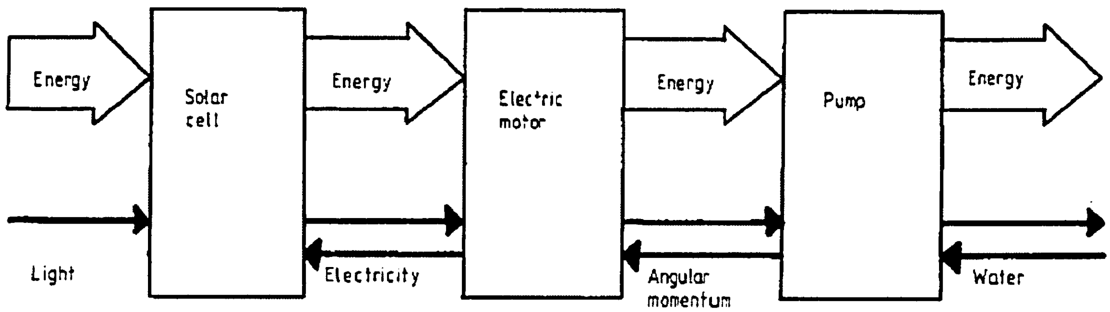


Figure 2.4: An example of a system with transceivers.

In the example illustrated in Figure 2.4, the solar cell, the electric motor and the water pump are transceivers. In the case of the transceiver, solar cell, the energy arrives with the carrier, light, and leaves with the carrier, electricity. Accordingly, in the case of the transceiver, electric motor, the energy arrives with the carrier, electricity, and leaves with the carrier, angular momentum; finally, for the transceiver, water pump, the energy arrives with the carrier, angular momentum, and leaves with the carrier, water.

Schmid remarks that the description of the function of a transceiver presented earlier is accurate only in ideal situations; in the case of real situations this seems to be more complicated. In expanding his reasoning he states that considering energy as substance-like in nature, leads to the assumption that it is a conserved quantity ('Footnote 1: All quantities which are generally conserved are substance-like, e.g. energy, entropy, …'; Schmid, 1982, p. 212). However, a transceiver does not give all the energy it receives from an energy carrier. Instead, by considering the conservation of energy principle, it is assumed that the energy unloaded to the transceiver is carried away not only by one but by two energy carriers. The energy carried by the second carrier is considered as 'the 'lost' part of the energy' (Schmid, 1982, p. 215) which is usually given as 'heat' to the surroundings and for which the term *cooling outlet* (Schmid, 1982, p. 215) is used. In concluding, Schmid states that: 'All 'real' energy transceivers have a cooling outlet' (Schmid, 1982, p. 215).

The Karlsruhe theoretical framework became the centre of a new debate concerning the instruction of the concept of energy within the science education research field. Warren (1983), in an article in which he examines the various aspects of the theoretical framework, strongly criticizes it and characterizes it as: '... unsound both scientifically and educationally' (Warren, 1983, p. 209). His main objection in relation to its scientific consistency concerns the proposed materialistic nature of energy which he rejects categorically. He states that within the theoretical framework energy is presented as: '... a 'magic fluid'' (Warren, 1983, p. 209) which can flow from one place to another changing its form according to its carrier and for which its quantity remains the same. Furthermore, he claims that this materialistic view of energy is in direct contradiction to the scientific view of the concept according to which energy is an abstract calculable idea, the 'capacity of a body for doing work' (Warren, 1983, p. 210).

A second objection in relation to the scientific consistency of the theoretical framework concerns the introduction of carriers for 'carrying' energy. As Warren claims, diverse entities such as light, fuel, hot water, angular momentum and 'electricity' (charge? current? or what?) (Warren, 1983, p. 211) are grouped to be considered as energy carriers. Furthermore, commenting on the statement made by Schmid (1982) that carriers are abstract quantities each of which is associated with a material object rather than with the object itself, he claims that such an approach leads to a great confusion of concrete and abstract ideas and remarks that: '... no reason has given for regarding the abstract ideas as 'carrying energy'' (Warren, 1983, p. 211).

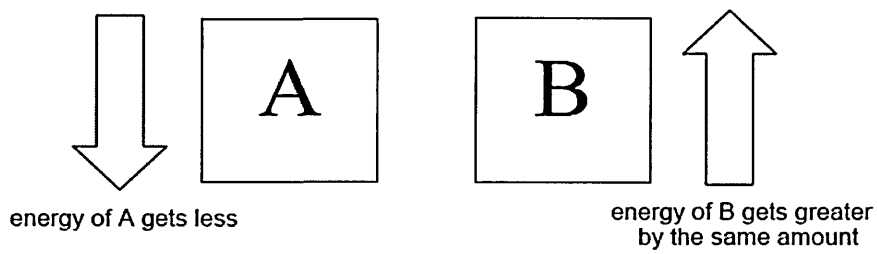
The main objection raised by Warren in regarding the educational validity of the Karlsruhe theoretical framework concerns the fact that it is based on everyday activities in which the processes involved can be described by the students using their everyday conceptions of energy. He states once again that energy is an abstract concept, '... a quantitative measure of the *condition* of the body, and must be distinguished very carefully from measures of *processes* such as work and heat 'transfer' (Warren, 1983, p.210). In clarifying this statement, he gives the following example: 'For example we should be clear that a domestic electric meter measures the work done by the generating station upon the household appliances; it does not measure the energy of anything as assumed by Dr Schmid' (Warren, 1983, p. 210). Concluding, he states that this approach for introducing energy is confusing and leads the students away from the scientific use of the concept.

A second objection made by Warren in relation to the educational validity of the theoretical framework is that energy is introduced early, at elementary level, as a primary quantity. He claims that young students cannot understand an abstract concept such as energy and much more the meaning of a primary quantity. In addition, he claims that: 'There is also a failure in logical consistency', and he expands his point of view arguing that: 'Energy has been said to be a primary quantity not derived from 'quantities such as mass, displacement, velocity and force'. Yet to explain energy Dr Schmidt invokes travel, which is meaningless without displacement and velocity. Further, when work must be done in traveling this is because of certain types of friction, which would very hard to describe without the explicit use of the concept of force'. Finally, he concludes that: 'There is nothing in this discussion that can give any meaning to a particular quantity to be called energy' (Warren, 1983, p. 211) and points out once again that such approach causes confusion in students' minds.

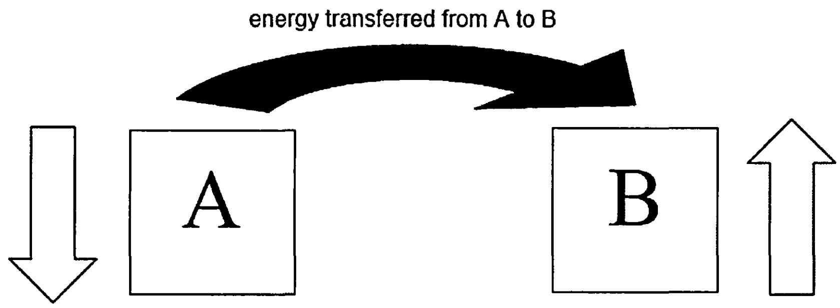
The Karlsruhe theoretical framework was reviewed, along with other theoretical frameworks developed for the instruction of the concept of energy, by Duit (1985). In a later article, Duit (1987) critically examined the substance-like consideration of energy in the light of both its scientific consistency and its instructional validity. Since the theoretical framework was already presented analytically, the following discussion will be focused on the critical examination and the conclusions which resulted.

Duit (1987) initiated his critical examination with the key question of whether energy should be illustrated as a substance-like quantity. He finally concluded that it is not possible for a definite answer to be given since a number of advantages as well as limitations and problems were revealed by the critical examination.

The substance-like consideration of energy was also discussed by Millar (2005). As he states: '... it is hard not to think of energy as 'something' that flows, or is somehow transferred, from place to place-rather than just thinking of it as a number that does not refer to anything 'real'' (Millar, 2005, p. 6). In clarifying his statement, he analyses the following example: 'Imagine two objects, A and B, that interact in a process of some kind. The energy of A decreases-and the energy of B increases by the same amount.



It is easy to see this as meaning that something (energy) has been transferred from A to B.



So we develop a model of energy as a kind of intangible substance that flows from place to place, as a way of making sense of energy conservation. This is, however, a model-which is not exactly in line with the scientific idea of energy-and it is helpful to keep this in mind as you use it' (Millar, 2005, p. 6-7).

On the other hand, Beynot, (1994) opposes a substance-like consideration of energy and particularly in introducing it as such within the school physics. In concluding his article, he states that: 'The concept of energy as an abstract quantity means that we do not need to worry about what it is. The erroneous idea that energy has substance-like qualities is thought to lie at the root of many of the difficulties that school pupils and higher education students have in attempting to unravel the workings of the physical world' (Beynot, 1994, p. 88).

2.9.1 DISCUSSION

In this section, some different ideas about energy were presented which raised another strong debate within the science instruction research. On the one hand, the inspirers of the Karlsruhe theoretical framework Falk and Herrmann (1977, 1978, 1979, 1981) and its supporter Schmid (1982) insist on a substance-like nature of energy. Based on the grounds of this consideration, they propose the early introduction of the concept of energy which takes into account the everyday notions of students about energy. On the other hand, Warren (1983) raises serious objections concerning the scientific and educational consistency of the Karlsruhe theoretical framework; he insists on the abstract nature of energy and on the definition that energy is the ability for doing work. Furthermore, he strongly opposes an early introduction of the concept of energy and particularly, he opposes taking into account the students' everyday notions.

However, a third group of researchers such as Duit (1985, 1987) and Millar (2005) admit at first that the 'materialistic' view of energy does not exactly coincide with the scientific view; but in the following, and in line with Falk, Herrmann and Schmid, they express the point of view that the substance-like consideration of energy firstly enables an early introduction of energy and secondly, it does not constitute a serious obstacle to a future more abstract consideration of energy.

The energy flow diagrams discussed by Schmid (1982, p. 213) can be reproduced into a single, general energy flow diagram, as that illustrated in Figure 2.5.

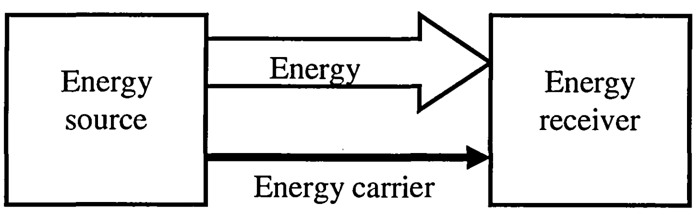


Figure 2.5: General form of a flow diagram.

From the above flow diagram, it is inferred that energy can be *stored* in both the energy source and the energy receiver; can be *transferred* by means of energy carriers; can be *transformed* when changing the kind of the energy carrier; can be *conserved* and; can be *degraded*. These five aspects of the concept of energy constitute an energy model which could indeed be used for the instruction of the concept in a comprehensive way. This could be true since, it could be very well applied to a description of the changes which occur in everyday situations and which the students might experience, in terms of energy.

However, the idea of energy carriers for the flow of energy is accompanied a number of inconsistencies. Firstly, the physical meaning of the need of carriers to carry energy is not explicitly explained. As Duit (1985, p. 85) remarks: 'The energy carrier concept leads to the notion that energy, so to speak, always 'travels by taxi' i.e. always flows together with the carrier in terms of both time and space. This conception is not tenable'. Secondly, as Schmid (1983, p. 211) pointed out, diverse in nature entities are grouped as the energy carriers. Again, what is the physical basis of including the particular entities in the group of energy carriers?

Overall, the Karlsruhe theoretical framework includes some useful ideas which could be used for the effective instruction of the concept of energy from an early stage. Within this, changes occurring and observed in everyday situations could be described in terms of energy flow from one place of a system into others, taking into account the procedures of store, transfer, transformation, conservation and degradation. And this provided that the idea of energy carriers is being eliminated since, in my view, it is considered as a difficult and confusing one and furthermore, it does not contribute to the pursued effective teaching and learning process.

2.9.2 INSTRUCTIONAL APPROACHES DEVELOPED FROM THE SUBSTANCE-LIKE CONSIDERATION OF ENERGY

The substance-like conception as well as some of the ideas included within the Karlsruhe theoretical framework were used as a basis for the development of new approaches to the instruction of the concept of energy. In the new approaches, the element of the 'energy carriers' (Schmid, 1982, p. 212) was eliminated since, as shown in the previous section, it was considered as problematic both scientifically and instructionally (see, for example: Duit, 1985, 1987, Warren, 1983). Instead, the notion of energy flow is used for energy transfer within systems or from one system to another.

In the following, two instructional approaches developed on the grounds of the substance-like consideration of energy are presented and discussed.

ENERGY AS A KIND OF FUEL

One of the instructional approaches which was based on the grounds of the Karlsruhe approach is that proposed by Duit (1985). According to the theoretical framework of this approach, the meaning of the physical concept of energy is characterized by the following five basic aspects (Duit, 1985, p. 68) (Figure 2.6):

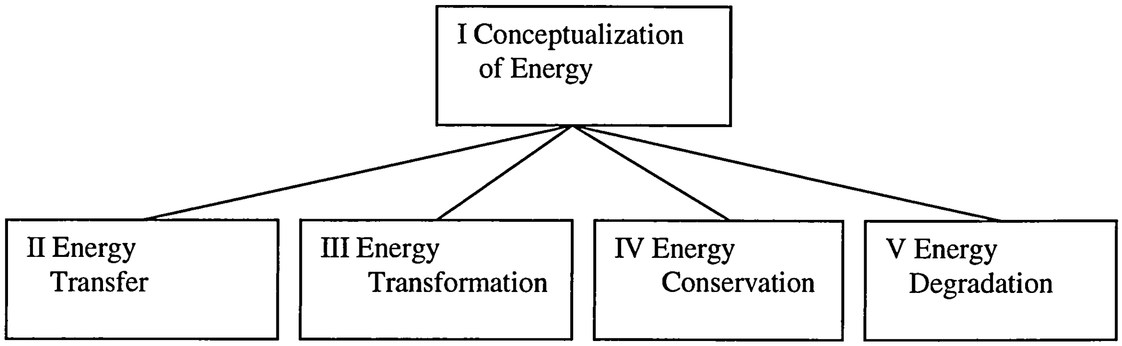
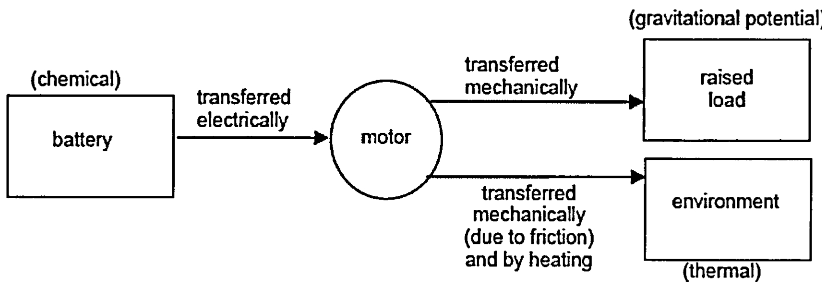


Figure 2.6: The theoretical framework for energy proposed by Duit.

In particular, within this theoretical framework energy is conceptualized as 'a general kind of fuel' (Duit, 1985, p. 93) which is needed in order for the physical and technological processes to take place and in turn, energy is provided by these processes. The processes have 'energy inputs and energy outputs' (Duit, 1985, p. 93). As he claims, the notion of energy as a general kind of fuel enables the early introduction (at the age of 12 as he proposes), not only of the aspect of energy store, but also the aspects of transfer, transformation, conservation and degradation both qualitatively and quantitatively.

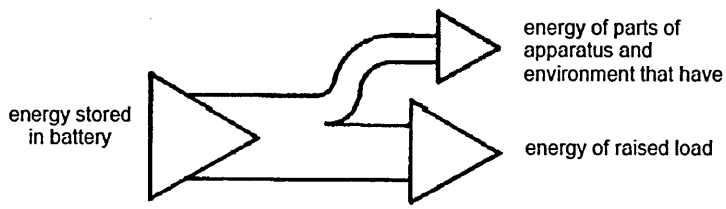
Another instructional approach based on a similar theoretical framework to that developed by Duit (1985), though more detailed, was proposed by Millar (2005). Millar suggests the early introduction of energy and energy resources as a good starting point. He expresses the point of view that energy supply problems should be considered by all citizens and thus, students should be taught from an early stage. He emphasizes the replacement of the word 'energy' with the word 'fuel' arguing that the use of the terms 'energy use' and 'energy consumption' might cause problems when introducing the aspect of conservation. Furthermore, he argues that the use of the terms 'fuel use' and 'fuel consumption' (Millar, 2005, p. 11) are more appropriate and at the same time accurate.

Furthermore, according to Millar the use of all five proposed aspects of energy could be effectively used for the description of events and processes of everyday life in terms of energy. These could also be represented diagrammatically, in terms of energy. He suggests two ways of such representations (Millar, 2005, p. 15): 'For example a battery connected to a motor, raising a load could be represented as follows:



Here the rectangles show the initial and final energy stores-and the circle shows a device which changes the way in which energy is being transferred.

Another way of representing the same process is to use a Sankey diagram (Millar, 2005, p. 15):



Concerning the above diagrammatic representations of events and processes, it can be noted that: in the first way, the transfer of energy is presented qualitatively with the energy stores and energy pathways be specified and also the parts in which these are found. In the second way, the transfer of energy is presented quantitatively with the triangles to represent the energy stores and the arrows the energy pathways. Furthermore, the size of the triangles represents the amount of energy in it whereas the width of the arrows, the amount of energy being transferred.

2.9. 3 DISCUSSION

The instructional approach proposed by Millar (2005) for the instruction of the concept of energy includes elements which may be characterized as potentially effective and applicable. The first element concerns the content of the theoretical framework on which its development was based. It includes the fundamental aspects of the concept of energy, namely, energy can be stored, transferred, transformed, conserved and degraded. The fact that within this theoretical framework, energy is conceptualized as a substance-like quantity could be considered as one of its negatives, since it does not strictly conform with the currently accepted concept of energy as an abstract quantity. On the other hand, this inclination could be well justified by the fact that this enables a more comprehensive way of representing energy and thus, it enables its introduction at an early stage. Duit (1985) and Millar (2005) claim that this inclination do not constitute a serious barrier to a future more abstract consideration of energy in more advanced work. Furthermore, Duit (1985) adds that in modern physics either the substance-like or the abstract nature of energy is valid since the concept of energy has been re-established and re-formulated on the grounds of the theory of probabilities within which energy is no longer localizable. From my point of view, energy is one of fundamental scientific concepts of great socioeconomic importance and thus, understanding of it within the accepted scientific views should be pursued through school instruction. Moreover, the substance-like consideration of energy should be avoided.

A second element which enables the instructional approach to be effective and applicable is the introduction of energy ideas through the elaboration of events and processes of everyday life. Furthermore, the order and the ways with which these are introduced gradually increase in difficulty, starting from the idea of energy store to the idea of degradation.

Finally, the visual representation of events and processes is another potentially efficient element of the instructional approach. It is my belief that the use of some kind of visual representations in the instruction of energy and, in physics in general, can very much contribute to the conceptual understanding of energy and other difficult physics concepts.

2.10 ENERGY TRANSFORMATION VS ENERGY TRANSFER

Many instructional approaches proposed for the instruction of the concept of energy are based on the model of energy flow within which the aspects of transfer and transformation hold a central role. In most of them, the emphasis is placed on the aspect of transformation rather than on that of transfer. The dominance of the aspect of transformation is aimed at the introduction of the idea of conservation. This could be achieved by regarding energy as a common characteristic of all processes which are investigated. In such an approach the implicit meaning, according to Duit (1985, p. 78), is: 'When transformations occur, energy produces energy and compensation can always observed (the contributions of some energy forms decrease, others increase to a correspond extent)'.

Much debate arose for the 'forms of energy' approach and various different objections have been raised by many researchers. Summers (1983) expresses an objection to formulations such as 'heat is transferred' claiming that they reinforce the notion that heat is 'something' contained in objects, which contradicts the currently accepted, by most physicists, the view of energy as an abstract idea. Mac and Young (1987) share this point of view and add to this that objections should be also raised to formulations such as the 'transfer of potential energy'. They justify their point of view claiming that potential energy should be considered as a property of an object and thus, not as something that can be transferred. In other words, Summers (1983) and Mac and Young (1987), state that a form of energy should not be treated as something which is contained in objects, rather as a numerical quantity. In addition, Duit (1985) argues that the 'forms of energy' approach entails the '... risk of presenting energy as a quasi-material substance and also debasing energy to a general explanation of everything (or nothing)' (Duit, 1985, p. 78).

Another strong criticism about the use of 'forms of energy' was expressed by Falk, Herrmann and Schmid (1983) characterizing them as '... inappropriate and conceptually even misleading' (Falk et al., 1983, p. 1074). As they claim, the use of the term 'energy form'

> '... is unsatisfactory because it easily leads to the misinterpretation that there are different kinds of energy, rather than emphasizing the simpler and physically more correct picture of energy as an unalterable substance' (Falk et al., 1983, p. 1074).

Taking as a starting point their argument that energy is a substance-like quantity and that it always flows simultaneously with at least one other physical quantity, they propose that 'forms of energy' should be abandoned and be replaced by the concept of 'energy carrier' (Falk et al., 1983, p. 1074).

An objection of another kind, concerning the emphasis placed on forms of energy was raised by Ellse (1988). He claims that: 'It draws attention away from the easier, more useful and important understanding of *energy transfer*' (Ellse, 1988, p. 427). Furthermore, he claims that the 'forms of energy' approach deals with the 'form' in which energy is manifested at different points rather than with the processes with which it is transferred from one place of a system to another or from one system to another. Furthermore, Ellse (1988) proposes that labels for forms of energy should not be used and that it would be more appropriate to refer to 'energy' being 'transferred' from one place to another instead of energy being 'transformed' or 'converted' from one form to another. Nevertheless, Millar (2005, p. 8-9) states that:

> 'Whilst this works well for some processes, however, it works less well with others. For example, consider the simple situation of an object falling from a height or sliding down a smooth slope. Here we are interested in the energy of the <u>same</u> object at the beginning and the end-and it seems clearer to talk about its potential energy having been transformed (or converted) into kinetic energy than to try to explain it using only the word 'transfer''.

The way with which energy is presented by teachers, authors and examiners in relation to the difficulties that students encounter in understanding energy was examined by Chisholm (1992). He claims that indeed some of these difficulties arise from the way of presenting the concept with the use of many names to define the 'forms' of energy. As Chisholm remarks:

> 'We hoped at one stage to avoid attaching names to different 'forms' of energy altogether, since energy is not defined in terms of its source. Energy is energy. But we decided to use a limited number of names for convenience, at the same time trying to limit the list' (Chisholm, 1992, p. 218).

The 'forms' of energy approach was also criticized by Mclldowie (1995) claiming that too much emphasis on a descriptive rather a qualitative presentation of energy causes problems. In adding to this, he remarks that not only the use of many names for energy causes problems but also the fact that they: '... do not actually define physical types of energy, but tend to refer to *situations in which energy is found ...*' (Mclldowie, 1995, p. 228). Furthermore, he claims that (Mclldowie, 1995, p. 229): 'Energy belongs to systems, not to single objects. It is never possible to be specific about the energy of a single object without reference to others'.

Another researcher among the many who raise objections to the use of the 'forms of energy' is Millar (2005). His first claim against them is that students just learn a set of labels which does not add much to their understanding of energy. A second point made by Millar against the use of the forms of energy approach is that it may (Millar, 2005, p. 8): '… lead to analyses of situations which introduce unnecessary variables that do not contribute to understanding'. Furthermore, Millar claims that in some cases, the use of the forms of energy approach may lead to incorrect analyses of the processes under study.

In contrast to the objections raised by many researchers, Papadouris, Constandinou and Kyratsi (2008) advocate the value of the use of 'forms of energy' and propose a theoretical framework for the instruction of energy from an early stage within which the notion of transformation holds a central role. In an article, they report on a study they carried out within the context of research project EKTEMA (it sets out to design, develop, and validate curriculum materials for energy, to be addressed to students aged 11-15 years old). The study aimed (Papadouris, Constandinou and Kyratsi, 2008, p. 444): '… to explore the ways in which students, aged 11-14 years, account for certain changes in physical systems and the extent to which they draw on an energy model as a common framework for explaining changes observed in diverse systems'.

Data were collected through the use of two research instruments: interviews with 20 students and an open-ended questionnaire which was administered to 240 students in whom, those interviewed were not included. Both the questionnaire and the interview protocol were structured in a similar manner. They consisted of two pairs of systems that illustrate a certain change (Figure 2.7) (Papadouris, Constandinou and Kyratsi, 2008, p. 449); for example, the rotation of electric and wind blades of the first system illustrated in Figure 2.7.

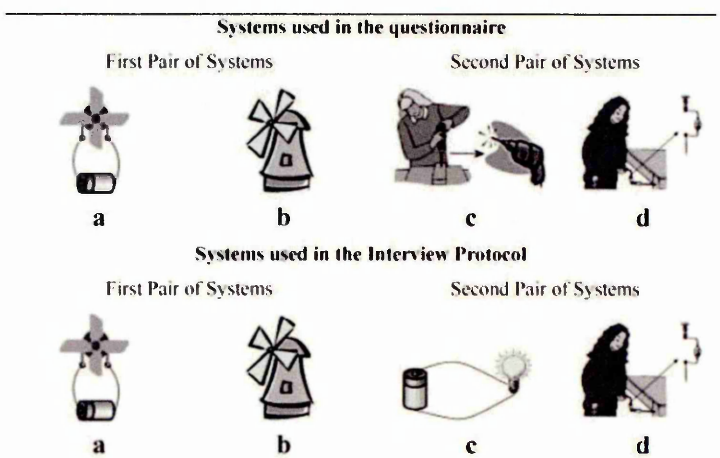


Figure 2.7: The systems included in the questionnaire and the interview protocol.

Students were presented with two probes for each pair of systems. The first asked the students to explain each individual change independently whereas the second, to provide an explanation which would account for both changes observed in each pair of systems. Furthermore, students who were interviewed were confronted with additional probes aimed to clarify their responses.

Among the various findings of the study, two are related to the debate as to whether an emphasis should be given on the ideas of 'forms of energy' and 'energy transformations'. According to the researchers, the first one concerns the fact that although students seem to consider energy transfer as a causal mechanism associated with changes, this was rather based on intuition; in addition, students do not seem to appreciate its explanatory power and cross-domain nature. The researchers claim that this finding could be justified (Papadouris, Constandinou and Kyratsi, 2008, p. 464): '... by students' tendency to constrain its scope to certain systems that include an apparent source (e.g., a battery), a receiver (e.g., a bulb) and a direct connection between them (e.g. through a wire)'.

For the second finding, the researchers claimed that the mechanism of energy transfer alone proved insufficient for the students in providing an adequate explanation for the changes illustrated in the systems under study. Commenting on this finding, they stated that this could be explained by the fact that in many of the students' responses, the mechanism of energy transfer was used as a base for explanations in an invalid manner.

Based on their findings, Papadouris, Constandinou and Kyratsi argue that (Papadouris, Constandinou and Kyratsi, 2008, p. 464): '... the idea of energy transformation could be used to complement and supplement any attempt to form a sufficient account for changes in terms of energy'. Also, they suggest the need for a coherent framework within which to embed the idea of energy transfer so as to help students develop a functional understanding about its role as a mechanism for explaining changes in a systematic and consistent manner'.

In concluding, the researchers propose a theoretical framework for the instruction of energy from an early stage, based on the grounds of the mechanisms of energy transfer and transformation. As they claim, this theoretical framework could be used to explain the observed changes in a variety of physical systems. Furthermore, they remark that within this, the idea of energy transformation holds an important role. In justifying the emphasis placed on the mechanism of transformation, they claim that changes in certain systems can be described more easily in terms of energy transformation rather than in terms of energy transfer, which is also supported by Millar (2005, p. 8-9). In expanding their reasoning, they use the following example (Papadouris, Constandinou and Kyratsi, 2008, p. 465):

> 'One such example is the system of a compressed spring that is released and is then allowed to return to its original state. In both states (when it is compressed and while returning to its original state) energy is stored in the same object (the spring), although in a different form (elastic potential energy when the spring is compressed and kinetic energy while it decompresses). This change can therefore be more easily explained through the mechanism of energy transformation rather than energy transfer'.

2.10.1 DISCUSSION

Many different objections were raised regarding the use of the forms of energy approach. Two main objections concern the critical issue of the nature of energy. The first of these is that the introduction of many 'forms' of energy entails the risk of creating the misconception that there are many kinds of energy and not one physical quantity. This is particularly true in the case of Cyprus National Curriculum for Physics for the first grade of upper secondary school in which the various forms are introduced without prior establishment of the key energy ideas, that is, without the prior introduction of an integrated theoretical framework for energy. Furthermore, the introduction of the various 'forms' independently reinforces the risk of being considered by the students as different kinds of energy. As a result, students are not provided with an understanding that the various 'forms' of energy are, in a manner of speaking, the various 'faces' of one physical quantity. In addition to this, students learn many labels and how to solve quantitative problems of each 'form' but in fact they often do not acquire an understanding of the concept.

The second objection is that, the use of the forms of energy approach entails the risk of regarding energy as a substance within the objects or as a substance which can flow from one place of a system to another rather than a property of an object or a system. The former is again quite true in the case of the Cyprus Curriculum for Physics for the first grade of upper secondary school which defines the use of definitions which explicitly implies this. As discussed in the previous section 2.9.3, the substance-like consideration of energy does not comply with the view of energy as an abstract quantity.

Another serious objection among the many that have been raised about the use of 'forms' of energy is the consideration of energy transfer processes such as electrical working, heating, sound and light as the corresponding 'forms' of 'electrical energy', 'heat energy', 'sound energy' and 'light energy'. The main argument which can be made here is that energy is a property of an object or a system. Taking for example the case of a simple electric circuit, there is no object or a system with a measurable amount of energy. Energy is transferred from one part of the system to another-in this case from the battery to other components of the circuit (and the environment)-by electrical working done on the electrons by the electrical forces of the electric field due to the potential difference between the poles of the battery.

As discussed at the start of this section, many approaches for the instruction of the concept of energy are based on the energy flow model in which the notions of transfer and transformation hold a central role. Much debate has taken place as to whether an emphasis should be placed on the notion of transformation rather than the notion of transfer; some researchers expressed the point of view that the notion of transformation should be abandoned as being ineffective in contributing to students' conceptual understanding of energy whereas others claim that the notion of transfer alone is ineffective in explaining the changes that occur in certain systems.

Within the context of a curriculum for physics which seeks the introduction of the concept of energy at an early stage, I believe that a more concrete way of presenting energy should be used. Although the use of an approach based on the 'forms' of energy seems to be effective, this should be avoided and an approach that is more compatible to the currently accepted scientific view of energy should be developed and used. My objections are grounded mainly on the fact that the 'forms' of energy approach seems to include serious scientific inconsistencies. Firstly, it seems to divert rather than focuses on the scientific view of energy as one single entity abstract in nature; secondly, 'heating', 'light', 'sound' and 'electrical working' are defined as 'forms of energy' rather than mechanisms/processes of energy transfer.

2. 11 ENERGY AS A CAUSAL AGENT

2. 11.1 ENERGY IS THE CAUSE OF CHANGES

In an attempt to introduce the concept of energy early in school physics and thus to avoid the use of the concept of work and the various problems arising from its use in the instruction of energy, McClelland (1970, 1979) proposed an instructional approach within which energy is introduced as the *cause of changes*. According to McClelland, the proposed instructional approach aimed to satisfy three important criteria: '... accessibility to the student, explanatory power, and coherence with what is generally accepted' (McClelland, 1979, p. 369).

Within the theoretical framework on which his instructional approach is based, he introduces the following ideas of energy: 'Changes occur; some things can cause changes, others cannot; things which can cause changes have energy; things which can cause changes include living things, moving things, things lifted up, things under elastic strain, hot things, batteries and so on; changes are caused in different ways by things with different forms of energy; changes can occur which start off with one form of energy and end up with any other; energy can be stored; bigger changes involve more energy than smaller changes; in a change the thing which causes the change loses energy (uses it) but something else gains energy, usually in a different form; there is as much energy, in some form, at the end of a change as there was at the beginning; a rapid change over a short time can be equivalent to a slow change over a long time' (McClelland, 1979, p.369).

As McClelland claims, there is an hierarchical sequence of concepts underlying those ideas. The sequence starts with the lowest, that is, the 'names of specific materials and processes used as examples', followed by the 'names of forms of energy', the 'interconvertability' of forms of energy, then 'energy as an entity', and ends with the highest which is, the 'conservation of energy' (McClelland, 1979, p. 369).

According to McClelland, the introduction of the energy statements may not have at first an explicit meaning to the students. As the instructional and learning processes evolve, these are progressively refined through the use of a variety of examples drawn from the empirical world and where appropriate quantified; at the same time, attention is paid on the students' intuitive conceptions.

In order that the meanings of energy statements become understood, simple mechanisms are initially used, described in terms of energy; in what follows, these descriptions are used for the description of new mechanisms. This learning procedure is repeated in a sequence of stages until the mechanisms themselves become understood and through them, the pursued meanings.

In an outline of the Hungarian curriculum for energy, Kedves et al. (1984) refer to a similar 'definition'. They state that: 'It must be emphasized that the textbook speaks of energy as a measure of the ability of a body or of a field to act in certain ways. Thus energy is not presented as an existing, objective reality or its property. Pupils appreciate it as a physical concept which characterizes a capability; i.e. the ability for change of an objective, existing reality' (Kedves et al., 1984, p. 109).

Duit (1985) raises objections concerning the meaning of the term 'change' which he characterizes as obscure. His main objection concerns the nature of the changes caused by energy and he claims that these are not explicitly defined by the term. Furthermore, he states that the presence of energy is not by all means a prerequisite for certain changes to occur such as the linear and the circular motion in a free-vacuum field. In addition, he claims that the obscure meaning of the term 'change' causes difficulties with the Second Law of Thermodynamics. He advocates his point of view stating that: 'The ability of a system to cause change is dependent on the amount of energy, but at the same time it is also determined by the value and type of the energy' (Duit, 1985, p. 79).

2.11.2 Discussion

As discussed earlier, McClelland (1979) stated that his proposed conceptual framework aimed to satisfy three main criteria; the first criterion was that the conceptual framework should be accessible to the students. Students often conceive energy in the experienced world as the cause of the events which they observe to occur. Statements like: 'Energy makes things move' or 'Energy makes humans live and be active' justify this assumption. In that sense, the idea of introducing energy as a causal agent within school physics is indeed a potentially accessible way, particularly in lower grades' curricula, since this is in no way in contradiction to their everyday conceptions of energy.

The second criterion posed by McClelland was that the conceptual framework should have an explanatory power. As discussed previously, students are exposed in their everyday life to a variety of changes as different kinds of processes take place in different physical systems. From a scientific point of view, the interpretation of these changes may involve different physical concepts, which may not be included in the students' range of knowledge, particularly in the case of students in lower grades. The introduction of the concept of energy as a causal agent offers a single explanatory framework which may be used by students for the interpretation of various different changes; thus, it is indeed a potentially powerful and usable explanatory framework for students.

Finally, the third criterion concerned the coherence of the conceptual framework with what is generally accepted. Within the scientific context, energy is not concrete; rather, it is an abstract mathematical idea which in any case is conserved. Thus, the idea of introducing energy as a causal agent is inconsistent with what is currently scientifically accepted for energy.

The inconsistency of the 'definition' with the current scientific view for energy could be accepted in favour of its potential accessibility and explanatory power, as far as it concerns the lower grades. In more advanced work, the students should be introduced to the scientifically accepted view for the concept. Here, two critical questions may be raised: 'How attainable might be the transition from the notion that energy is the cause of changes to the scientific view that energy is an abstract calculable and conserved quantity?' and, 'How possible would be a smooth alteration of the students' conceptions without the cause of confusion or misconceptions? One possible answer to these questions might be that these instructional goals could be achieved but with difficultly. This kind of answer could be justified by the fact that the notion of energy as a causal agent is both reinforced and retained by the everyday use of the concept in the same manner. Thus, the conceptualization of energy as the cause of events should be avoided even in lower grades.

2. 11.3 ENERGY IS NOT THE 'GO' OF THINGS

Ogborn (1986) remarks that in order for a change to take place, there should be a cause; nevertheless, the cause is not energy. As he states: '... energy is *not* the 'go' of things, despite the common belief that it is. That is, the possession of energy is *not* what drives, gives potential for, explains, or accounts for change' (Ogborn, 1986, p. 30).

Millar (2005) adds to the view that energy should not be considered as a causal agent for changes in two ways: Firstly, energy is not a mechanism and in that sense, changes could be explained by taking into consideration other physical concepts which may be involved in them. Secondly, energy is a conserved quantity; in cases in which it is considered as a causal agent, the evolution of processes only in one direction and not in the reverse cannot be explained, despite that it is still conserved.

In his work Ogborn (1986) claims that the occurrence of changes should be attributed in fact to another physical concept, which is very close to that of a fuel, namely *entropy* or *free energy*. Thus, the change in free energy at the completion of a process could be described by the equality:

$$\text{(free energy change)} = -\,T\ \text{(total energy change)} \qquad (1)$$

where T is the temperature of the environment, assumed constant (Ogborn, 1986, p. 31).

Furthermore, he clarifies that as a process takes place, energy is the quantity which takes part in the occurrence of a change whereas entropy or free energy is the one which decides whether or not the change will occur. When a spontaneous event takes place, free energy decreases and at the same time entropy increases, which is in accordance to equality (1), whereas energy remains unchanged. Entropy could be assumed as a measure of a system's disorder. For a system which is in a state of equilibrium, the value of its entropy is maximum and at the same time, also according to equality (1), the value of its free energy is minimum. Of course, in the equilibrium state the occurrence of any change is not possible.

As pointed out by Ogborn, when a change takes place, it is free energy which is used up rather than energy. Due to the fact that the observed changes occur in the environment of the earth, he suggests that the term 'exergy' is a more appropriate one for the concept of free energy and to replace the concept of energy.

Ross (1988) also expresses the point of view that in everyday language, the meanings which are attributed to the word 'energy' are close to what physicists call 'free energy' in scientific language and he adds that they are in conflict with school physics. He claims that: '... the second law is just a common experience ...' (Ross, 1988, p. 439), meaning that the idea of degradation is involved in most everyday processes and, he suggests that it should be introduced in school physics before the first law of conservation of energy. Furthermore, he claims that introducing the second law before the first, would contribute to the decrease of the number of misconceptions since the idea of degradation will be introduced first and thus, help students to understand that energy is not 'used up' but rather becomes 'useless', and is in any case conserved. Ross admits that the term 'free energy' is a difficult one to be used by students and suggests the terms 'fuel-value' or 'available energy' (Ross, 1988, p. 439), instead of the term 'exergy' proposed by Ogborn. In addition, he states that there is an equivalency in the terminology used for the same scientific quantity within the social, school science and scientific language which can be illustrated as in Figure 2.8 (Ross, 1988, p. 440):

energy (to the man in the street)	=	**fuel value** or **available energy** (proposed use in school)	=	**free energy** or **ΔG** (to the scientist)

Figure 2.8: Equivalent terms used for energy within the social, school science and scientific context.

Solomon (1982) like Ross, also suggests that the Second Law of Thermodynamics should be introduced in school physics before the First Law and before general education ends. However, concepts like entropy and free energy and the Second Law of Thermodynamics are quite difficult and abstract to be understood by students as well as to be introduced in a comprehensive manner by science teachers. Solomon (1982) suggests that the instruction of the Second Law could be possible with a reformulation of it in which simpler and more familiar terminology would be used. Furthermore and according to Solomon, a possible reformulated version could be:

'In all energy changes there is a running down towards sameness, in which some of the energy becomes useless' (Solomon, 1982, p. 419).

Solomon justifies the proposed version by stating that: 'The use of the word 'sameness' instead of *entropy* or *disorder*, has been dictated by the difficulty pupils have in thinking of the degradation of energy towards the *same* temperature, pressure, dilution or height above some reference level, as an increase of *disorder*. The movement towards microscopic uniformity, which such energy changes produce, actually corresponds more closely to order than disorder in the children's eyes' and she ends up by stating that: 'In practice this version of the Second Law feels intuitively right and is easy to use' (Solomon, 1982, p. 419).

In relation to the proposed version of the Second Law, Solomon remarks that it places emphasis on *change from difference* (Solomon, 1982, p. 420) and that: '... it does indicate the importance of the *driving forces of difference* in a way that pupils can recognize and use' (Solomon, 1982, p. 420).

2.11.4 DISCUSSION

The theoretical framework proposed by Ogborn (1986) suggests a 'conceptualistic view' (Warren, 1982, p. 295) for the instruction of energy, that is, on the grounds of its current scientific view. In spite of its scientific consistency, the proposed theoretical framework could create difficultly in being applied in teaching interventions within the context of school physics. My main argument concerns the fact that it suggests the instruction of a difficult abstract concept such as energy, with the use of an advanced physical law, the Second Law of Thermodynamics, which requires an understanding of an even more difficult and abstract concept, that of entropy or free energy. A more comprehensive version of the Second Law indeed had been suggested by Solomon (1982) in order to be introduced early in school physics. Still, even using this simpler version, its use is confined to a qualitative treatment since a quantitative treatment requires the acquisition of advanced mathematical skills by the students.

The instructional proposals made by Ogborn (1986, 1990), Ross (1988) and Solomon (1982) respectively, explicitly suggest as a starting point for the instruction of energy the aspect of degradation at an early stage. As outlined (see, for example, Ogborn, 1986, Ross, 1988), the word 'energy' is used in everyday language with a meaning which is more close to the word 'fuel' and which in scientific language corresponds to the concept of 'free energy'. Since energy is considered as a fuel, statements used in everyday life such as 'energy is used up' or 'there is a loss of energy' imply that it is considered as a non-conserved quantity, a conception which is in contradiction to its scientific meaning and consequently, to what is taught within the school physics lessons. This is due to the fact that this seems to happen in everyday processes. The introduction of the concept of energy with the use of the Second Law of Thermodynamics and thus the introduction of the idea of degradation, explicitly leads to the assumption that energy is not 'used up', rather it is stored in kinds of stores which cannot be further used. In the light of this assumption, the instruction of the conservation of energy principle may follow smoothly, as was pointed out by Ross (1988). Furthermore, the instruction of the aspect of degradation prior to the aspect of conservation potentially enables a better understanding of the latter.

Another advantage, of the early introduction of the degradation of energy, was pointed out by Duit (1985). This concerns the fact that an understanding of the idea of degradation enables the students to acquire a clear understanding of the crucial social and economical problems which are related to energy supply.

Duit (1985) underlying the importance of the early introduction of degradation states that: 'Without the aspect of energy degradation, understanding of the physical energy concept is incomplete' (Duit, 1985, p. 89). I will share the point of view that all aspects of the energy concept should be introduced at an early stage in order conceptual understanding of the concept be promoted.

In a later piece of work, Ogborn (1990) also suggests the use of the idea of *differences* to replace the concept of negative entropy and free energy for the explanation of the observed changes. As he states:

> 'In summary, we tend to think of energy as the creative power to generate differences. We are not wholly wrong to do so, since there is something which has power. But it is not energy, it is difference itself. It takes a difference to make a difference' (Ogborn, 1990, p.82).

In this new approach of introducing energy within the context of school science, Ogborn (1990) states that in a closed system, there are limits as to what can happen and what cannot; one such limit is that the total energy cannot change. In that sense, the values of all variables which describe the state of a system vary in a manner in which the total energy remains unchangeable. Changes in a closed system are possible if three prerequisites are fulfilled. Firstly, a difference should be contained in the closed system, secondly the total energy should remain the same at the end and thirdly, there is a trade of some energy (Ogborn, 1990).

Ogborn distinguishes two kinds of difference: (a) Dynamic differences, that is, differences in force and motion and, (b) Thermodynamic differences, that is, differences in temperature and diffusion (Ogborn, 1990, p. 82). In relation to the first kind of differences, Ogborn presents the following example (Ogborn, 1990, p. 82): 'The first kind of difference is one associate with springs. If the total energy would change if the length of the spring changed, and nothing else changed, then something can happen. Of course, just this event *cannot* happen, since it would change the total energy. But if the total energy would also change if the speed of a mass in the sealed room changed (and nothing else changed-again impossible), then the spring can change length and the mass can speed up or slow down'.

For the second kind of differences, he presents the following example (Ogborn, 1990, p. 83): 'The second kind of change is that which created the storm. Differences in temperature between the Sun, Earth and space, producing on the Earth temperature differences between the poles and the equator and between the lower and upper atmosphere, produce the weather'.

Differences, as already mentioned, may drive changes. When these changes are accomplished, differences are diminished. It should be remarked that spontaneous events do not result in increasing differences; in the cases in which there is an apparent increase, there is a simultaneous decrease in difference of some other physical quantities in the system.

Finally, Ogborn suggests that a classification of kinds of change would be useful in order for a particular kind of problem to be distinguished from another. The kinds of change which he introduces are the following (Ogborn, 1990, p. 85):

1. *Equilibrium*

Where there is no difference, no change and which lasts forever if undisturbed.

2. *Dying difference*

Where a difference, often small and near equilibrium, spontaneously dies out and equilibrium is reached. No other differences need to produced.

3. *Productive dying differences*

Where a difference, in vanishing produces other differences on the way. A storm blowing down a tree is an example, as is a fire, or an engine.

4. *Trapped difference*

Where a difference, created by other larger differences in the past, is kept as it is and has no coupling via which to decay. Fuel is trapped difference.

Continuing differences

Where a difference is kept in being by the continual vanishing of difference from some other source.

2.11.5 INSTRUCTIONAL APPROACHES DEVELOPED FROM THE IDEA OF DIFFERENCES

The ideas presented earlier were used by Boohan and Ogborn (1996b) for the development of a teaching approach for the instruction of energy and the physical and chemical change from an early stage within the project 'Energy and Change'. The instruction included the use of abstract pictorial representations.

Within this approach the instruction of energy and physical and chemical changes is considered to start at the age of 11 years with the introduction of the procedures of filtration, dissolving, distillation and crystallization. For that purpose, a set of abstract pictures were created. The activities assigned to children included the matching of a number of processes to the picture that best represented it. An example of such activity is the process of the preparation of a cup of 'instant' coffee which matches the pictures of Figure 2.9 (Boohan and Ogborn, 1996 b, p. 13).

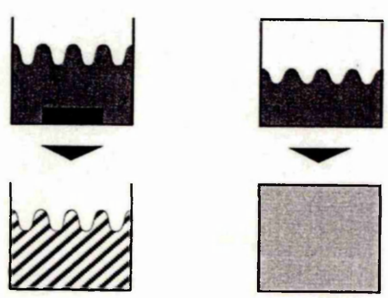


Figure 2.9: Abstract representations illustrating the preparation of a cup of 'instant' coffee.

The waved-surface pictures in Figure 2.9 represent a liquid and the plain box a gas, the darker shading indicates higher temperature whereas the lighter shading lower temperature, and, the stripes a salt dissolved in a liquid. Also, the dark triangles represent the direction of time and thus, they connect the initial and the final state of the substances involved in the process.

Another set of abstract pictures was used for the instruction of the concepts of temperature and heat for children 12 years old. An example of an activity assigned to the children was to select one of the pictures shown in Figure 2.10 (Boohan and Ogborn, 1996 b, p. 14) which best represents a room which is heated by radiators.

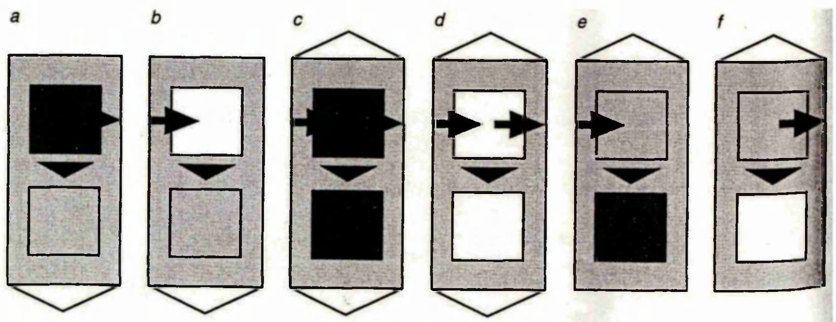


Figure 2.10: Abstract representations illustrating heating and cooling procedures.

In the pictures of Figure 2.10, the darker shading represents again higher temperature whereas the lighter shading lower temperature; the horizontal arrows represent the flows of energy, the triangular downward arrow at the bottom the spontaneous occurrence while the non spontaneous is represented by the triangular upward arrow at the top; the dark arrows in the middle represent the passing of time and thus, they connect the initial and the final state of a process.

As Boohan and Ogborn report, after a discussion the class agreed that (Boohan and Ogborn, 1996 b, p. 14): 'The room is kept hotter than outdoors, losing energy through the windows and getting it from the radiator and thus, the picture that best represents the situation under study is picture c.'

Boohan and Ogborn (1996b) suggest the use of the teaching approach of the interpretation of changes in terms of differences at higher age levels in advanced physical and chemical systems. Furthermore, in classes of advanced level more abstract pictorial representations could be used as well as formulae for both the qualitative and the quantitative study of processes.

In concluding, Boohan and Ogborn (1996b) claim that within this teaching approach the students, whether they are involved only in a qualitatively or in both a qualitatively and a quantitatively study, should understand at the end that the discussion of processes of that kind involves the use of the idea of differences. It is clear that the evolution of these processes is based on the logic that the distribution of matter and energy is possible only if it is driven by differences. In the case of spontaneous processes, differences tend to disappear as soon as the processes have taken place. On the other hand, in the case of non spontaneous processes, it is possible for differences to be created and maintained.

The idea of introducing differences to describe changes is an innovative and interesting one. This theoretical framework replaces that within which the Second Law of Thermodynamics is expressed in terms of negative entropy and free energy and enables the instruction of the Second Law in a more comprehensive and less 'scary' way to the students. The idea of differences could indeed be related by students to changes observed at the evolution of a process in a physical system and be described in terms of energy trade. I share the view expressed by Boohan and Ogborn that the idea of differences could be developed early in the instruction of the concept of energy in a qualitative way and provided that simple systems are analyzed. Also, it could be used in more advanced physics courses for the description of the changes observed in more complicated systems and be expanded into a quantitative study. Furthermore, the idea of differences represents a simplification invented for the introduction of the concepts of negative entropy and free energy and thus, of the Second Law of Thermodynamics. This is in any means in contradiction to the current scientific view of the concept of energy.

The visual representations created by Boohan and Ogborn (1996b) for the instruction of the idea of differences to describe changes are also innovative. However in my opinion, these are very difficult to understand and for that reason, they need much effort from students to match them to the corresponding processes. In addition, some of them (see, for example: Boohan and Ogborn, 1996 b, p. 14) are complicated, due to the fact that they include much information, particularly for the age level of students to whom they are addressed.

Stylianidou (1997) reported an evaluation of the teaching approach developed within the project 'Energy and Change'. The report was based on the progress achieved by three 11-12 year old pupils who were studying in an urban primary school of London in mixed-ability classes. The attainment of these pupils was slightly lower than the national average.

The topics which were selected for this age level were 'Air/Materials' and 'Life'. The pupils were involved in activities in which physical and chemical change takes place like dissolving, mixing, crystallization and diffusion. The activities included the use of abstract pictorial representations some of which were presented earlier. Pupils were exposed to such activities for a time period of eight months.

The data collected consisted of (Stylianidou, 1997, p. 92):

- interviews conducted with pupils before and after introducing each topic;
- observational records of the science lessons kept by the researcher;
- copies of the pupils' written assignments;
- copies of the teacher's completed evaluation forms for each of the project's activities they used in the classroom;
- interviews conducted with science teachers in the school.

As the researcher claims, results from data analysis collected through interviews with pupils, in observations of the science lessons and the pupils' written assignments revealed that overall, the three pupils worked successfully with the activities, they made use of the introduced terms and they understood the abstract pictorial representations of the kind of processes. Furthermore, the abstract pictorial representations seemed to contribute to the achievement of higher levels of generalization in their explanations of physical, chemical and biological change than they would achieve without being exposed to them.

Williams and Reeves (2003) reported an instructional approach for the instruction of energy which was based on Boohan's and Ogborn's (1996b) idea of using abstract pictorial representations. They defined three prerequisites upon which they developed their instructional approach. According to these, it should:

- be scientifically consistent although not rigorous in all of its parts;
- make use of 'labels' meaning to make use of 'forms' of energy;

- be fun.

The instructional material consisted of a set of cards of abstract diagrams each of them corresponding to a form of energy and a set of name cards-cards on which the name of a form of energy was written. The researchers considered that a system of classification of the forms of energy and some simple rules would also useful. For that reason, they decided to include ten forms of energy which they separated into two groups: (a) Energy transfers and, (b) Potential energies (Williams and Reeves, 2003, p. 150-51). Energy transfers included the forms 'kinetic', 'heating', 'radiation', 'electrical work' and 'sound' whereas potential energies included the forms 'nuclear', 'internal', 'chemical', 'elastic potential' and 'gravitational potential'.

Williams and Reeves state that the classification of forms of energy gives rise to a problem which is the inclusion of kinetic energy in the energy transfers group although it is a form of stored energy. On the other hand, it could not be included in the potential energies group since it is not a form of potential energy either.

The next step in their work was the creation of diagrams which would best represent each form of energy. As they commented, they decided to create their own more simple diagrams since they considered Boohan's and Ogborn's abstract-looking pictures to be difficult to be understood by the students. For each diagram, they formulated a definition for the corresponding form of energy.

The diagrams and the definitions which correspond to each form of energy are shown in Figure 2.11 (Williams and Reeves, 2003, p. 151).

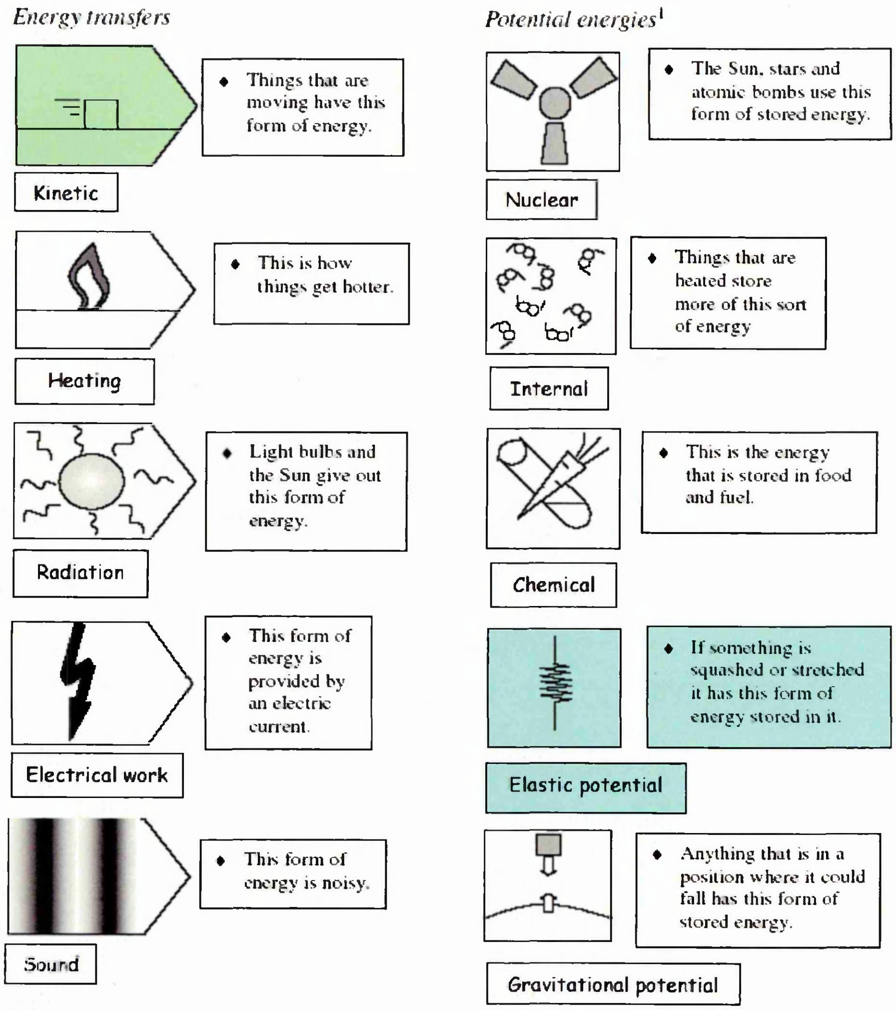


Figure 2.11: Visual representations and definitions of forms of energy.

The sequence of instructional interventions is initiated by providing each pair or individual with both a set of the diagram cards and the name cards. The first activity which was assigned to the students was to match every diagram card to the correct name card. Hence, using a PowerPoint presentation the researchers introduced to the students the definition of each form of energy and furthermore, the various sources of energy. At this stage, the students were able to construct energy chains such as that shown in Figure 2.12 (Williams and Reeves, 2003, p. 152).

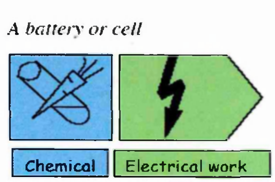


Figure 2.12: An example of a section of an energy

In the following teaching interventions, the students were introduced to transformers, namely, to devices which convert the form of energy without storing it. At this stage, students could construct energy chains such as the one shown in Figure 2.13 (Williams and Reeves, 2003, p. 152).

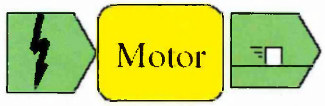


Figure 2.13: An example of a simple energy chain.

The next step was the introduction of the conservation of energy principle. A discussion about where the energy ends up and about energy dumps preceded the formal introduction of the principle. The researchers used the chain presented in Figure 2.14 (Williams and Reeves, 2003, p. 152) during their instruction.

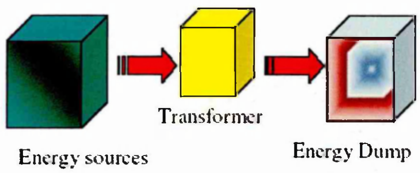


Figure 2.14: General form of an energy chain representing the energy conservation.

Students in their turn were able to construct energy chains like that of Figure 2.15 (Williams and Reeves, 2003, p. 152).

Figure 2.15: An example of an energy chain.

Finally, the researchers introduced the idea of efficiency and conducted a discussion about its meaning. At this stage, students were able to construct more complicated energy chains, one of which is presented in Figure 2.16 (Williams and Reeves, 2003, p.153).

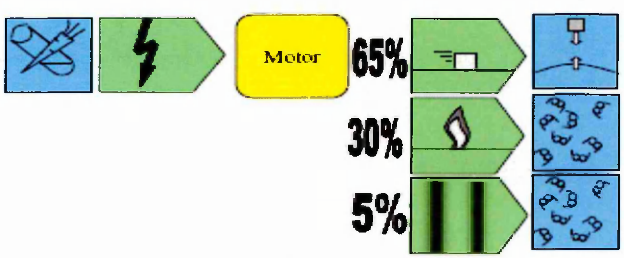


Figure 2.16: An example of a more complicated energy chain.

The researchers pointed out that for students age 11-14 years, the instruction of energy could end at this point; for students aged 14-16 years it could proceed to the introduction of Sankey diagrams.

In evaluating their instructional approach, Williams and Reeves claim that this was effective throughout all age levels and abilities, except for the case of the very lowest ability classes the students of which failed to gain an understanding of the diagrams. Students succeeded in constructing more complicated energy chains than they could construct if they were involved in any other teaching approach.

2.11.6 DISCUSSION

Concerning the proposed Williams and Reeves instructional approach for energy, I shall focus on the following points: firstly, the visual representations created by the researchers were, as was intended, less abstract and thus much simpler and comprehensive for the students of ages 11-14 to whom they are addressed, than those created by Boohan and Ogborn (1996b). Also, I share the researchers' point of view that the use of visual representations for the instruction of the concept of energy is a potentially powerful instructional tool. I add to this that they are a powerful instructional tool given that they are created after careful consideration of their content in relation to the way of representing it; in other case, misconceptions might be created.

My second point concerns the proposed 'forms' of energy and their categorization into two groups. In relation to the 'forms' of energy under the group-name 'energy transfers' many researchers, (see, for example: Warren, 1982 , Millar, 2005, Lawrence, 2007) with myself included, claim that heating, radiation, electrical working and sound are mechanisms or processes of energy transfer and not 'forms' of energy. In addition, kinetic energy, as Williams and Reeves also remark, is an energy store; furthermore, I consider that the content of this group departs from the current scientific view even that these simplifications were made for the sake of instructional convenience. For the second group, the researchers used the term 'potential energies' to name in fact 'energy stores'. I can hardly understand the underlying instructional purpose of the use of the term 'potential energies' instead of the more general 'energy stores' or 'stored energies' in which kinetic energy could correctly be included.

2.12 ENERGY WITHIN THE CONTEXT OF PHILOSOPHY AND THE HISTORY OF SCIENCE

In expanding their research work within the project EKTEMA presented and discussed in section 2.10 and, the project EPIKOITE, Constantinou and Papadouris proposed an integrated approach for teaching energy to students in the age range 11-14 years, that is, to students of upper primary/middle school in two subsequent papers (Constantinou and Papadouris, 2012, Papadouris and Constantinou, 2011). Setting as a starting point the question 'what is energy, why do we need it and how we use it?' (Constantinou and Papadouris, 2012, p. 164), the researchers developed their teaching approach for energy taking a philosophically-informed perspective. Specifically, they suggest the introduction of energy as an entity, abstract in nature, which is invented in the context of a theoretical framework that seeks to facilitate the interpretation and prediction of the changes and interactions within and between physical systems drawn from various domains. In that way as they stress, energy is introduced as a unifying construct for interpreting the changes occurring in a variety of physical systems. Within this theoretical framework, a qualitative conceptualization of energy is constructed with four key aspects: transfer, transformation, conservation and degradation. As the researchers claim: '... the features of energy transfer and form conversion could be drawn upon to provide interpretations for changes occurring in a wide array of systems. On the other hand, the features of energy conservation and degradation allow for the deviation of predictions about changes that cannot take place or changes that are very likely to occur spontaneously, respectively' (Constantinou and Papadouris, 2012, p. 170).

Discussing how the proposed teaching approach of energy indeed addresses a response to the fundamental question posed, the researchers make the following claims for each sub-question of it. For the sub-question 'what is energy?' they state that: '... students are guided to appreciate energy as a theoretical framework that has been invented in science to facilitate the interpretation of changes occurring in physical systems'; for the sub-question 'why do we need it?' they state that: '... and guides students to identify the value of energy as a unifying framework for the analysis of changes occurring in physical systems regardless of the domain they are drawn from and; regarding the sub-question 'how do we use it?' they state that: '... seeks to help students appreciate that energy can be used in science for the analysis of change in physical systems' (Papadouris and Constantinou, 2011, p. 976).

The researchers provide a detailed account of the structure and the content of the teaching materials included in their teaching sequence in both papers. The teaching sequence consists of a sequenced series of activities most of which are carried out online. Furthermore, the teaching approach based upon the *Physics by Inquiry*

Pedagogy (Mc Dermott and the Physics Education Group at the University of Washington, 1996, as it is cited by (Papadouris and Constantinou, 2011, p. 967).

As it is described, the activity sequence is organized into three main sections in such a way to promote conceptual understanding of energy. The first section focuses on the '*nature of energy* as a construct' (Papadouris and Constantinou, 2011, p. 967). In this section, philosophically-oriented activities are included aiming to address specific aspects of the Nature of Science (NOS) that could support the discussion about the nature of energy. The second section focuses on the '*value of energy* in science' (Papadouris and Constantinou, 2011, p. 967). In particular, the activities included stress on the unifying character of energy in analyzing the changes observed in physical systems regardless of the domain they are drawn from. Finally, the third section focuses on the '*elaboration of energy as a theoretical framework for analyzing changes* occurring in physical systems' (Papadouris and Constantinou, 2011, p. 967). The structure plan of the activity sequence is illustrated in Figure 2.17 (Constantinou and Papadouris, 2012, p. 167).

In the first section, the specific aspects of NOS included to support the discussion about the nature of energy as a construct were: '(i) the distinction between observation and inference; (ii) the role of theories in science and their relation to observations; (iii) the tentative nature of theories; (iv) the role of creativity and human invention in formulating and elaborating theories; and (v) the connections between theories and models' (Constantinou and Papadouris, 2012, p. 168).

For the introduction of the first aspect of NOS, the researchers adapted an activity originally proposed by Lederman and Abd-El-Khalick (1998). Regarding the introduction of the other four aspects of NOS, the researchers developed a set of activities focusing on two narratives drawn from the history of science. Specifically, Aristotle's theory of *natural place and natural place and natural motion* and Laviosier's *caloric theory* were drawn upon. In particular, Aristotle's theory was used to interpret the observed way the various objects moved whereas Laviosier's to provide an account for the outcome of the interaction between objects being at different temperature.

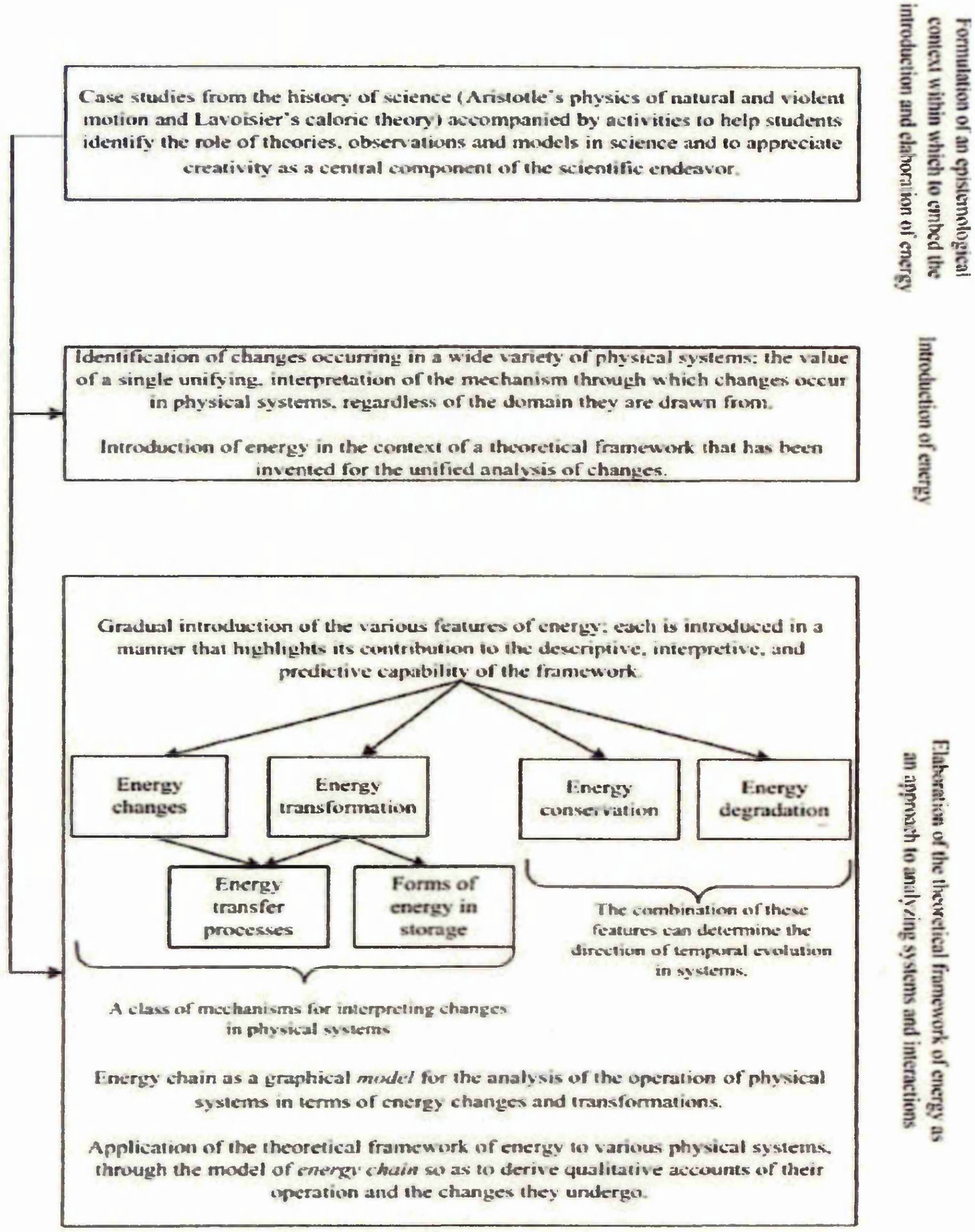


Figure 2.17: Structure plan of the proposed activity sequence.

The second section focuses on the introduction of the proposed theoretical framework of energy. Firstly, students are presented with computer-animated representations of physical systems in which certain changes take place and are asked to suggest a possible mechanism to interpret each of these changes. Hence, students are asked to suggest a single interpretation that could account for changes occurring in a range of physical systems. Energy is introduced as a theoretical entity within this framework; assuming that there is energy in a physical system which can be transferred from one part of it to another causing some of its other properties to change, students are provided with a unified perspective for interpreting diverse changes in a range of physical systems.

The third section of the activity sequence includes the elaboration of the theoretical framework of energy introduced in the second section and according to the researchers this seeks to increase the interpretive and descriptive power of the theoretical framework. Students are first introduced with the idea that energy manifests itself in various forms, the *forms of energy in storage*, depending on the physical system under study. Also, students are introduced to the idea that energy can be transferred from one part of a system to another through various processes, the *processes of transferring energy*. At this point it should be mentioned that the researchers emphasize the importance of students to differentiate between the forms of energy in storage and the processes of transferring energy and state that a systematic attempt is made throughout the third section to achieve this goal. Supporting their statement with relevant literature, they claim that this differentiation is often either not appreciated by students or not sufficiently addressed though instruction. Furthermore, some forms of energy in storage and some processes of transferring energy are illustrated in the cards of Figure 2.18 (Papadouris and Constantinou, 2011, p. 971).

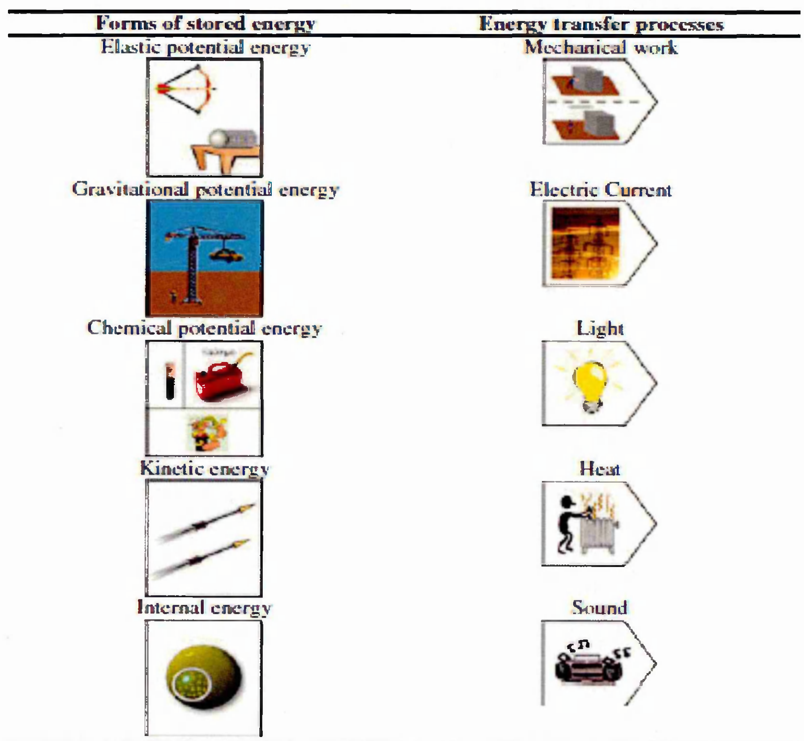


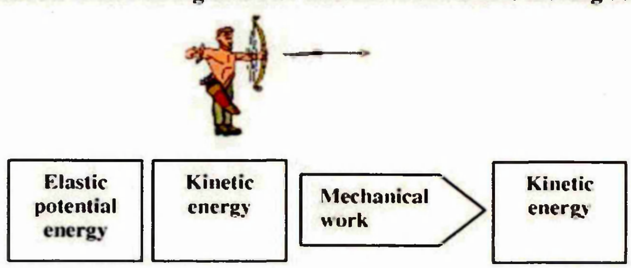
Figure 2.18: Cards of some forms of energy in storage and processes of transferring energy.

At this stage, students are engaged with activities in which they are asked to provide verbal interpretations. Then, they are introduced with the idea of an energy chain as a graphical means for interpreting the changes occurring in a system. The various forms of energy are depicted with a rectangle-shaped card whereas the processes for transferring energy with an arrow-shaped card. Thus, the energy chain for the description of the behavior of a physical system consists of an arrangement of rectangles and arrows. As the researchers claim, the use of rectangles and arrows stresses the distinction between the forms of energy in storage and the processes of transferring energy. Furthermore, emphasizing the use of energy chains as models of a system's behavior they state that:

> 'One important issue to be noted is that while the model of energy chain is intended to facilitate the application of the theoretical framework of energy to individual systems, it should be stressed that its overall objective is to provide a consistent and unified approach for the analysis of diverse physical systems drawn from essentially any domain of physics' (Constantinou and Papadouris, 2012, p. 169).

An example of verbal and graphical energy description is illustrated for the system of Figure 2.19 (Constantinou and Papadouris, 2012, p. 169).

An archer releases the stretched string in a bow and the arrow starts moving at a high speed.



The elastic potential energy that is initially stored in the stretched string is converted into kinetic energy. The string exerts a force on the arrow and it transfers energy through mechanical work, which is then stored in the form of kinetic energy of the arrow.

Figure 2.19: An example of verbal and graphical energy interpretation of the changes observed in the system.

2.12.1 Discussion

The teaching approach proposed by Constantinou and Papadouris could be considered as an interesting one of a series of proposals taking the 'forms of energy' perspective presented and discussed in sections 2.9 and 2.10 respectively. This includes an innovative part, namely the introduction of fundamental aspects of Nature of Science such as theories and models and their role in science with the use of narratives drawn from the history of science, to facilitate the introduction of the theoretical framework of energy. Focusing on the theoretical framework, although developed according to the 'forms of energy' approach, it lies on a more scientifically consistent ground. Specifically, energy is introduced as a unified, abstract in nature entity, which is invented to facilitate the interpretation of diverse changes in an array of physical systems. This consideration of energy is indeed in accordance with current scientific beliefs.

In spite of the attempts of the researchers to ground their forms of energy-based theoretical framework on a more scientifically consistent framework dealing with the weaknesses of this approach and their claims that: '… the *forms of energy* approach is both coherent and consistent' (Constantinou and Papadouris, 2012, p. 178) at various points of their papers, a serious objection could be raised concerning its ability to effectively promote understanding of the scientific meaning of energy. This objection emanates on one hand from the belief that a forms of energy-based theoretical framework could not by its origin as a theoretical construct to address explicitly and thus effectively, the fundamental aspects of energy as abstract in nature and as a single entity. As presented and discussed in sections 2.9 and 2.10, the origin of the 'forms of energy' approach lies on the substance-like consideration of energy, with this substance flow from one part of a system to others. On the other hand, this emanates from my experience as a physics teacher; students often hold a set of pre-instructional views for energy in which the materialistic nature appears strong; thus, a forms of energy-based approach, most probably would fail in establishing understanding of energy within its current scientific context. Furthermore, this objection is strengthened by statements made by the researchers such as:

> 'Engaging students in epistemological discourse about the role of models in science is expected to help them develop the sense that reasoning about energy as a substance-like entity that flows from one part of the system to another presents a simplified representation, which despite being convenient and intuitively appealing, fails to capture important aspects of the construct of energy. The most important of these relates to its immaterial and abstract in nature. In this way, it would become possible to help students gradually appreciate that while it might be acceptable to use the energy chain model for the analysis of a given system, it is always necessary to appreciate its limitations and be able to switch between this model and the more abstract nature of energy as an invented, quantitative construct' (Constantinou and Papadouris, 2012, p. 177).

As it is explicitly inferred by this statement, the researchers expect through their teaching approach that young students of 11-14 year to deal not only with the difficult scientific concept of energy but also to distinguish between this and the inconsistent, according to current scientific beliefs, substance-like representation of energy adopted in an energy chain, which actually entail in the 'forms of energy' approach. This expectation is in my opinion, not an 'ambitious' (Constantinou and Papadouris, 2012, p. 177) but most probably an unfeasible one to be achieved for students of the age group targeted.

Turning the discussion on the innovative part of the teaching approach, namely, the first section I shall focus on the following points: first, in justifying the philosophical orientation of their teaching approach, the researchers claim that it is important to engage students in epistemic discourse to support science teaching from young age and that this is consistent with findings of studies reporting that it is possible to impact on young students to develop understanding on aspects of NOS. A concern which arises here relates to whether aspects of NOS such as theories, models and their role in science, which are not concrete ones, could be addressed effectively to students of age 11-14 year.

A second concern relates to the appropriateness of the materials selected to introduce the specific aspects of NOS, namely the two narratives from the history of science. Aristotle's theory of natural place and natural motion and Lavoisier's caloric theory are already complicated by themselves, dealing with phenomena which involve fundamental physical ideas and processes such as gravitational force, heat and thermal equilibrium and are developed on their inspirer's intuitive perceptions of these phenomena. Thus, it is believed that the use of these two narratives as a basis for developing understanding of the non- concrete ideas of NOS most probably would not result to the pursued outcome to students aged 11-14 year. Furthermore, their use might result to strengthening initial intuitive ideas the students often hold for gravitational force and heat, similar to those of Aristotle and Lavoisier, a fact that might arise difficulties to future formal teaching of these.

A third consideration relates to the time which should be devoted for effective teaching of the aspects of NOS included in the first section of the teaching sequence. Taking into consideration the non-concrete nature of these ideas and the age range of students to which they are addressed, I would argue that sufficient time should be devoted to pursue understanding. However, the researchers do not clarify the number of lessons devoted in their teaching sequence for the introduction and elaboration of these ideas; they only refer to revisiting them in the second and third section.

A fourth and last concern relates to teaching of the first section of the activity sequence by primary teachers and middle school physics teachers. University studies nor Pre-service Training at the Cyprus Pedagogical Institute do not include Nature of Science Modules. Thus, teaching of the aspects of NOS will essentially require prior training of the teachers.

2. 13 ENERGY IS AN ABSTRACT MATHEMATICAL QUANTITY

Lawrence (2006) proposed an approach for the teaching of energy for students aged 11-14 years within the Supporting Physics Teaching 11-14 project (SPT11-14, 2006). Within this approach he introduced an energy model in which, physical changes which are observed in a system, as a physical process takes place in it, can be described in terms of energy changes. Due to the fact that the quantitative description with the use of mathematical calculations is not available for these ages, an approach was found with the development of qualitative visual representations of energy changes.

According to this energy model, energy is a unifying concept, abstract, calculable and conserved in nature. Energy can be found in 'energy stores' (Lawrence, 2007, SPT11-14, 2006) which can be filled or emptied. Energy stores are defined '... as places where one can pin down quantities of energy by calculation' (Lawrence, 2007). Depending on the calculating mechanism, energy can be found in various different stores, eight of them are defined as follows (Lawrence, 2007):

Store of energy-energy stored changes when:

- Gravity: an object alters its height above a planet.
- Kinetic: an object speeds up or slows down.
- Thermal: an object warms up or cools down.
- Elastic: an object is stretched or squeezed.
- Chemical: reactants combine or separate to give products.
- Vibration: a mechanical wave has its amplitude increased or decreased.
- Electric-magnetic: magnets or electric charges are pulled apart or allowed to come closer together.
- Nuclear: nuclear particles are rearranged, for example in fission or fusion.

The above energy stores are represented as it is shown in Figure 2.20:

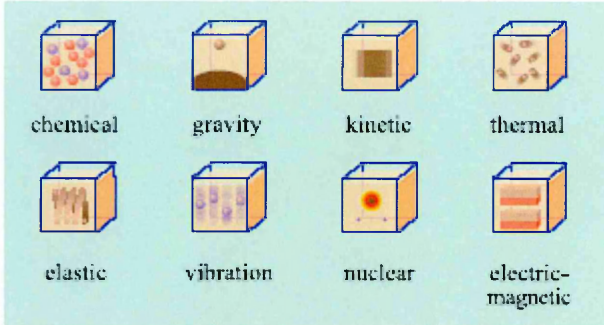


Figure 2.20: Representations of energy stores.

Energy stores can be filled or emptied along 'ways' or 'pathways' (Lawrence, 2007). Pathways provide information about the process or mechanism involved when energy is shifted from one store to another and also about the quantity of energy being shifted. There are various different pathways along which energy can be shifted, four of them are the following (Lawrence, 2007):

- Electrical working (electrical pathway)
- Mechanical working (mechanical pathway)
- Heating by particles
- Heating by radiation (including visible light)

The above pathways are represented in Figure 2.21.

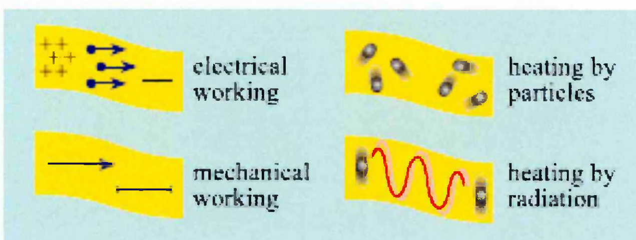


Figure 2.21: Four pathways with which energy can be shifted.

As Lawrence proposed (2007, SPT11-14, 2006), changes which are observed in a system, as a physical process is progressed in it, can be described in terms of energy changes or in other words, as the depletion of an energy store with the simultaneous filling of others, with energy being shifted along a specific pathway. As energy is shifted from one store to others, its quantity remains unchangeable, that is, it is conserved. By representing energy changes as the emptying and filling of energy stores along pathways, the quantitative description in terms of energy is made possible, although this is a non-numerical depiction.

During the analysis of the physical changes which are observed in a system as a process is progressed, it is equally useful and important to develop two different kinds of descriptions: the 'physical description' and the 'energy description' (Lawrence, 2007, SPT11-14, 2006).

An issue on which much attention has to be paid, (Lawrence, 2007, p. 406) is the explicit distinction between the energy description and the physical mechanisms effecting the changes which determine the places to seek energy. Energy descriptions do not describe causal mechanisms, that is, energy is not a mechanism that explains how or why things happen. An example of physical and energy description of a process is shown in Figure 2.22:

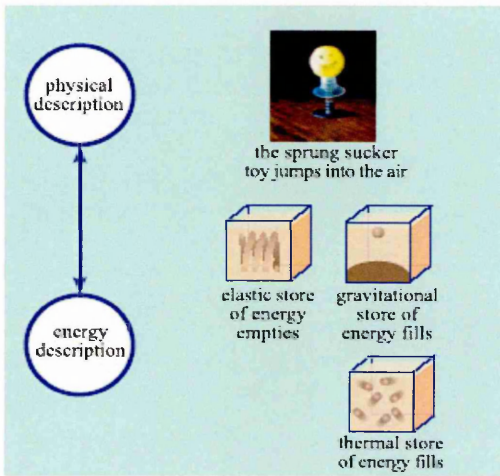


Figure 2.22: Physical and energy description of a process.

Another issue to which attention has to be paid, according to Lawrence (2007), is the selection of the physical process which will be studied. The process must be chosen wisely, not including unnecessary complexities, and its physical description be done carefully so as to clearly describe the changes which take place, before any attempt of an energy description. Furthermore, due to the fact that different points in the progression of a process can be described resulting in different outcomes, it is essential that the start and the end of the process be clearly determined. For that purpose, a pair of snapshots has to be selected, one for the start and one for the end of the process respectively. An example is shown in Figure 2.23:

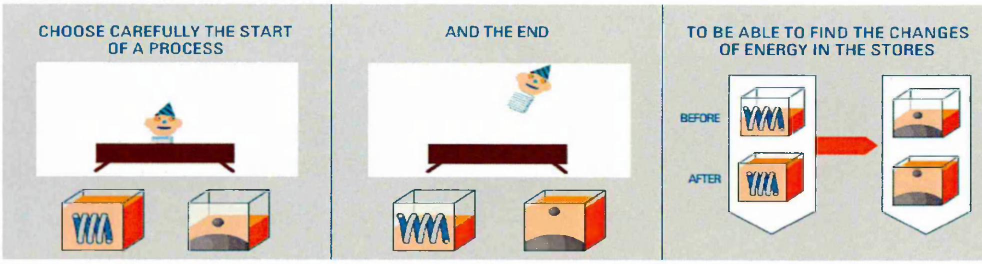


Figure 2.23: Snapshots for the start and the end of a process.

Like Millar (2005), within the SPT project the use of a Sankey diagram is proposed for the quantitative representation of the changes of energy in the energy description of a process. In that an arrow notation is used to represent energy shifting from store to store. The thickness of the arrow is a measure of the quantity of energy shifted along a pathway. In order for the conservation of energy to be represented correctly, the total thickness of the arrows before the occurrence of an event must be equal to the total thickness of the arrows after the occurrence of the event.

An example of a Sankey diagram representing the energy changes is shown in Figure 2.24.

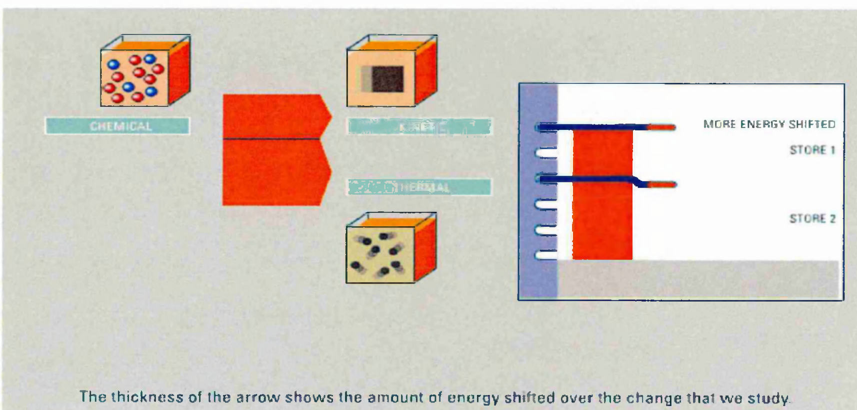


Figure 2.24: Sankey diagram

More complex Sankey diagrams representing both the start and the end states, how much energy is shifted, to which stores and along which pathways can be built (Figure 2.25).

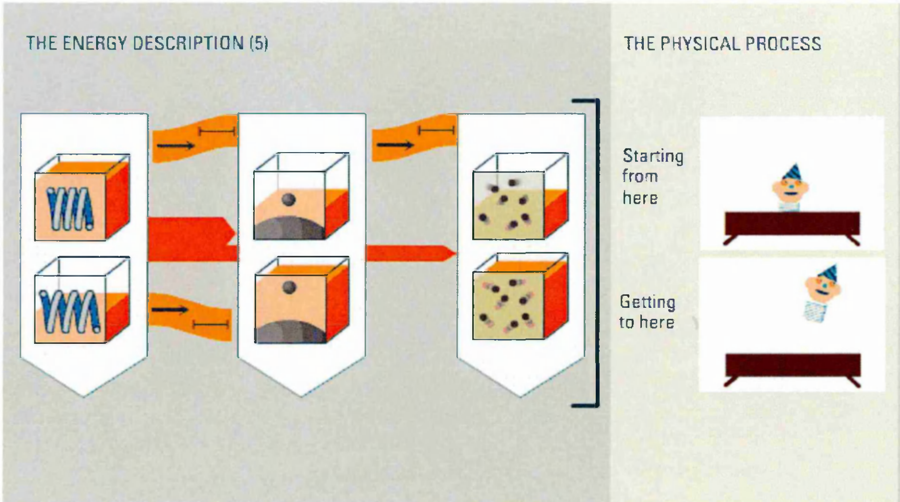


Figure 2.25: A Sankey diagram for a complex system.

The Sankey diagram in Figure 2.25 represents the energy description of the physical process involved when the toy leaves the table and rises up to its maximum height. At the start of the process, the spring of the toy is compressed and thus, the energy of the system is in the elastic store of the compressed spring. As the spring begins to stretch, the elastic store is emptied with its greatest amount of energy (top thick arrow) being transferred along a mechanical working pathway (top pathway) to a gravitational store as the toy rises. At the same time, a smaller amount of energy (bottom thinner arrow) of the elastic store is also transferred along a mechanical energy pathway (bottom pathway) into a thermal store of the toy and the surroundings.

Comparing the complex version of Sankey diagrams to the simpler one, Lawrence (SPT11-14, 2006) remarked that the simpler version has the disadvantage that the orange fluid does not appear to be conserved and on the other hand it has the advantage that it is more consistent with the current practice. Moreover, for the representation of energy changes he recommends either the use of stores with pathways or the use of at least single stores with Sankey diagrams.

Finally, Lawrence (SPT11-14, 2006) recommends that it is best to avoid drawing energy chains to show energy transfers in a system (Figure 2.26a). In the case of a complex system where the progression of a process includes many states, he recommends to deal with one step at a time and execute the calculations by considering a facet of each state. Thus, the energy description of a complex system might have the form shown in Figure 2.26b.

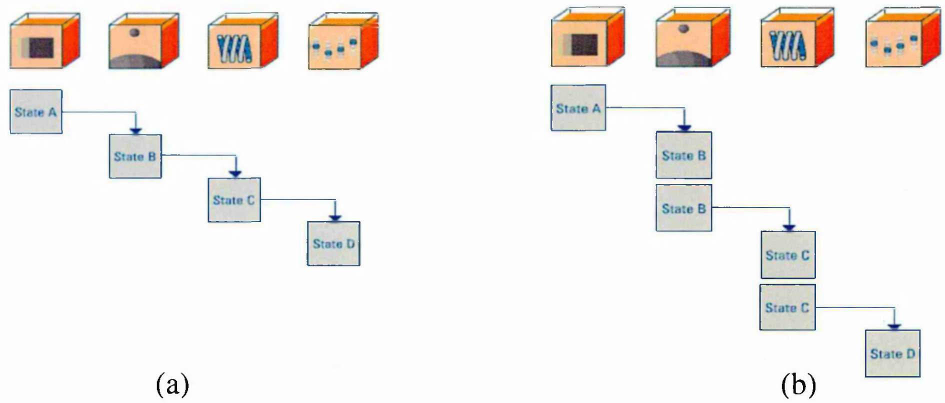


Figure 2.26: (a) An energy chain, (b) Energy description by a sequence of states.

It should be noted that Millar (2005) also argued against the inclusion of intermediate stages in the analysis of a physical process and for placing the focus on the initial and the final ones. As he claims, the inclusion of the intermediate stages increases complexity which does not contribute to understanding.

2.14 SUMMARY

This chapter shows that much interest has been focused on the teaching and learning of energy over the past three decades. This work has followed two main directions: the investigation of the students' interpretations about phenomena and events where scientific interpretation draws upon energy and the development of innovative instructional approaches for teaching the energy concept.

Studies carried out with students in a range of all ages and various nationalities revealed that energy is conceptualized as:

- something which is exclusively associated with animate objects;
- a causal agent stored in specific objects;
- something associated with force and motion;
- a fuel;
- a fluid, an ingredient or a product.

In particular, the students' alternative interpretations were categorized in the following seven conceptual models:

a. The Anthropocentric Model

Within the anthropocentric model energy is associated with living organisms and specifically with human beings and also with objects which are considered to possess human characteristics (Black and Solomon, 1983; Kruger, 1990, Solomon, 1983, Stead, 1980; Watts and Gilbert, 1985).

b. The Depository Model

Within the depository model specific substances, objects or media such as fuels, food and batteries can store energy, need energy or consume energy which is stored in them. Energy is considered as the causal agent which is stored in specific objects (Ault et al., 1988, Gilbert and Pope, 1982; Kruger, 1990; Solomon, 1983; Watts and Gilbert, 1985).

c. The Ingredient Model

Within the ingredient model energy is associated with fluids or ingredients that are dormant and are released suddenly by a trigger (Watts and Gilbert, 1985).

d. The Activity model

Students who hold the activity model associate energy with motion, force and activity (Brook and Driver, 1984; Duit, 1981; Gilbert & Pope, 1983; Kruger, 1990; Stead, 1980; Orfanidou, 2007, Watts and Gilbert, 1983).

e. The Product Model

Within the product model energy is viewed as a kind of by-product of a situation that is generated, is active, and then disappears or fades (Kruger, 1990; Watts and Gilbert, 1985).

f. The Functional Model

Those who hold the functional model percept energy as a fuel the amounts of which are limited (Ault et al., 1988, Duit, 1981; Solomon, 1983a; Stead, 1980, Watts, 1983a).

g. The Flow-transfer Model

Finally, within the flow-transfer model energy is considered as a fluid which can flow from one object to another (Gayford, 1986, Duit, 1981, Stead, 1980, Orfanidou, 2007, Watts and Gilbert, 1985).

The critical study of the instructional approaches proposed brought up various key teaching and learning challenges associated with the energy concept. As far as it concerns the 'conceptualistic' view proposed by Warren (1982) according to which 'energy is the ability (or capacity) for doing work', it seems that three main problems arise from its use. Firstly, it confines the instruction of energy to upper grades since it requires abstract thinking and advanced mathematical skills necessary for an understanding of the abstract concept of work. Secondly, it does not facilitate acquisition of the basic aspects of the energy concept. Thirdly, there is a risk the definition be used by students as a 'brief paraphrase of the term 'energy'' (Duit, 1985, p.78) and retained when introducing the energy concept in areas other than mechanics within which is mainly well established.

In the Karlsruhe theoretical framework proposed by Falk, Herrmann (1977) and Schmid (1982), energy is seen through a 'materialistic' perspective. According to this, energy is considered as a substance-like quantity which can be stored in a system and flow in a particular form from one system to another. The flow of energy is always accompanied by the flow of at least one other substance-like quantity, which 'carries' energy. Although the substance-like consideration permitted a more pictorial treatment of energy on one hand and thus an early introduction of the concept and it facilitated the acquisition of the basic aspects of the energy concept on the other hand, it was abandoned since the idea of the 'energy carriers' was considered as problematic both scientifically and instructionally.

Turning to the various instructional approaches developed on the grounds of the notion of energy flow, the one predominated even in the present is that in which the transformation aspect holds a central role. Here, although the 'forms of energy' approach facilitates the early introduction of the concept, it seems that two main problems related to the critical issue of the nature of energy are raised by its use. First, the introduction of many 'forms' of energy entails the risk of creating the misconception that there are many kinds of energy and not different 'faces' of one physical quantity. Second, the use of 'forms of energy' approach entails the risk of regarding energy as a substance within the objects or as a substance which can flow from one place of a system to another than as a property of an object or a system.

The 'forms of energy' approach was incorporated in a philosophically informed instructional sequence proposed by Constantinou and Papadouris (2011, 2012). According to this, energy is introduced as an entity, abstract in nature, which is invented in the context of a theoretical framework that seeks to facilitate the interpretation and prediction of the changes and interactions within and between physical systems drawn from various domains. Furthermore, fundamental aspects of the Nature of Science such as theories, models and their role in science are employed to support the instruction of energy.

In an attempt to introduce energy in an understandable way at an early stage, McClelland (1970) proposed an instructional approach within which energy is considered as the cause of changes. In turn, Ogborn claims that 'energy is *not* the go of things' (Ogborn, 1986, p. 30) and that the occurrence of changes should be attributed to another physical concept, which is very close to that of a fuel, named entropy or free energy. The theoretical framework proposed by Ogborn proved to be very difficult to be used in teaching interventions within the context of school physics. This was because it suggests the instruction of a difficult abstract concept such as energy, with the use of an advanced physical law, the Second Law of Thermodynamics, which requires an understanding of an even more difficult and abstract concept, that of entropy or free energy.

In a later piece of work, Ogborn (1990) suggested the use of the idea of differences to replace the concept of negative entropy and free energy for the explanation of the observed changes. Within this theoretical framework, it is considered that in a closed system, there are limits as to what can happen and what cannot; one such limit is that that total energy cannot change. Changes in a closed system are possible if three prerequisites are fulfilled: first, a difference should be contained in the closed system, second the total energy should remain the same at the end and third, there is a trade of some energy. These ideas were used by Boohan and Ogborn (1996b) for the development of an instructional approach for teaching energy and chemical change at an early stage with the use of visual representations. However, although the visual representations created for the instruction of the idea of differences to describe changes were innovative, they were very difficult to be understood and for that reason, they needed much effort to match to the corresponding process. In addition, some of them were complicated, due to the fact that they included much information, especially for the students' age level targeted.

Another theoretical framework for energy was proposed within the SPT11-14 project (2006, Lawrence, 2007). According to this, energy is a unifying concept, abstract, calculable and conserved in nature. Changes which are observed in a system, as a physical process is progressed in it, can be described in terms of energy changes, that is, as the emptying of an energy store with the simultaneous filling of other stores, with energy being transferred along a specific pathway. As energy is transferred from one store to others, its amount remains the same.

Among the proposals reviewed, the ideas within the SPT11-14 project (2006, Lawrence, 2007) were chosen to form the grounds on which the theoretical framework of the innovative teaching sequence proposed in this doctoral thesis would be developed. This decision was based firstly on the consideration of those ideas as consistent to the current scientific beliefs for energy; secondly, on the consideration that these include those elements for the development of a teaching sequence which would promote conceptual understanding of the concept of energy and; thirdly that it allows for quantitative treatment. These issues are discussed in more detail in Chapter 4, where all steps of the design and development of the research-informed teaching sequence are presented.

CHAPTER 3- RESEARCH METHODOLOGY

In the previous chapter, perspectives on the energy concept and the teaching and learning of energy were considered.

This chapter presents a detailed account of the decisions made concerning the design of the research carried out in this doctoral thesis. Emphasis is placed on the decisions made for the selection and development of the research instruments and the kinds of data analysis used for the evaluation of the research-informed teaching sequence proposed in the next chapter.

3.0 INTRODUCTION

In this chapter, the design process of the methodological steps followed in setting up the design study carried out in this doctoral thesis is presented. This process included decisions about the structure, the context and the form of the study carried out. Attention is placed on the decisions made for the evaluation of the research-informed teaching sequence. These mainly concerned the effectiveness in promoting conceptual understanding of the concept of energy. It was decided that a mixed method be used, involving both quantitative and qualitative analysis. Analysis included the comparative study of the findings of data collected from a group of students taught through the research-informed teaching sequence to those collected from a group receiving 'normal' teaching. This included an in-depth study of the developing understanding of the concept of energy of students taught through the 'new' teaching.

3.1 AIM OF THE RESEARCH

The aims of the study were to:

- Review the international literature on teaching and learning about the concept of energy.
- Identify the key teaching and learning demands associated with the energy concept as described in the Cyprus National Curriculum for age 15-16 year.
- Develop a research-informed instructional sequence to address these teaching and learning demands.
- Implement and evaluate the instructional sequence.
- Review the overall strengths and weaknesses of the sequence including the views of the teacher.

The research questions for the study were as follows:

RQ1.What concepts of energy are used by a Cypriot cohort of upper high school students prior to teaching? The answer to this question would serve two key purposes: first, to check whether the initial conceptions of the Cypriot students on energy coincide with some of those reported in the international science education literature; if yes, to identify these specific conceptions and; whether there are any other initial conceptions not yet identified. Information on these issues would be considered in the design and the development of the innovative instructional approach to increase its effectiveness in promoting conceptual understanding of the concept of energy. Second, to determine the initial conditions of the study, that is, whether or not the sub-cohort of students which would be taught through the research-informed approach was initially equivalent to that receiving the 'normal teaching'. Information on the initial equivalency of the two sub-cohorts would be used to establish the validity of the findings of the study as required by Research Methods literature. Specifically, this would be used in the comparative study of the effectiveness of teaching in the two sub-cohorts and to the formulation of an answer to RQ2. Furthermore, information on the students' initial conceptions on energy would be used for the development of the energy learning trajectory of a small-group of experimental students and to the formulation of an answer to RQ3.

RQ2. How do the conceptions and learning of the sub-cohort of Cypriot students taught through the research-informed approach compare with those following 'normal teaching' after instruction? The answer to this question aimed to reveal whether the proposed research-informed teaching sequence is effective in promoting conceptual understanding of the concept of energy in comparison to current curriculum for energy and the usually used teacher-centered approach. Furthermore, if effective, to gain insights on the degree of its effectiveness compared to that of 'normal teaching'.

RQ3. How do the understandings of the energy concept, of a small sub-group of students, develop during the lessons of the research-informed approach? This question aimed to provide qualitative, detailed insights to illuminate the quantitative findings revealed through the answer to RQ2.

3.2 RESEARCH APPROACH

After defining the aims and formulating the questions to be addressed in the research, work was focused on the design and development of the methodology which would be followed in carrying out the research.

In setting up the research methodology, decisions were made on a number of key issues. The first in the sequence concerned the context within the research would be carried out. Taking into account that the research would be a part of a doctoral thesis and not of a broader educational research project and that it is concerned with the comparative evaluation of an innovative teaching sequence, it was decided that this would be carried out in real educational settings and in particular in a single upper high school with no more than two intact classes participating. Furthermore, in order for this comparison teaching and learning design be arranged, it would essentially take a great deal of organization; this could be really achieved in a single school, given the resources available to the researcher.

The next decision to be made concerned the method to be used. After a careful consideration of this issue it was decided that, this should be based on the kind of data required to be collected for the three research questions to be addressed. It was decided that, a mixed method should be used, involving both qualitative and quantitative analysis. More explicitly, in order the first research question be answered, data concerning the students' pre-instructional interpretations about the energy concept should be collected. This could be facilitated with the administration of a pre-test to all participating students, both to those who would be taught through the innovative research-informed teaching sequence and those who would be exposed to 'normal' teaching. For the second research question, data concerning the students' understandings on the energy concept after the teaching intervention would be required. The administration of a post-test also to all participating students would facilitate the collection of this data. Furthermore, in addressing the first research question, comparisons between the Cypriot students' pre-instructional interpretations and those reported in studies from other countries should be conducted. For addressing the second research question comparisons between students following the experimental and the comparison group teaching would be made. These in their turn, could provide a clear evidence of the effectiveness of the proposed innovative research-informed teaching sequence. The analysis carried out is described and discussed in detail in section 3.6.1.

However, the administration of the pre and post-test could not alone provide adequate data for testing all hypotheses of the research and the formulation of conclusions. As was discussed earlier, these could provide the first and second research questions with a full set of data whereas only some data for the third question. Further consideration resulted in the use of other data collection instruments for the enrichment of data sets regarding the third research question. In particular, it was decided that first, interviews with a sub-cohort of experimental students and with the experimental teacher and second, the inclusion of short-length diagnostic probes which would be administered to the experimental students during the teaching intervention could serve this goal. The number, the content and the precise time of administration of the short-length diagnostic probes were decided at a later stage, after the development of the research-informed teaching sequence. An answer to the third research question could be obtained through a qualitative analysis of data collected using all the above data collection instruments. The qualitative analysis carried out for the experimental students and the experimental teacher's interviews is described and discussed in detail in section 3.6.2.

Furthermore, it was decided that video recordings of the lessons for both the group of students who would be taught through the innovative teaching sequence and the group of students who would be exposed to 'normal' teaching would be made, to monitor the extent to which these were performed according to their design.

The third issue on which a decision was made related to the kind of research to be carried out. Since the research-informed teaching sequence would be tested in a real educational setting, the *quasi-experimental approach* (Campbell and Stanley, 1963, p. 34) suggests itself for the reasons outlined below. Further review of the research methods in education literature (see, for example: Wiersma, 1986) resulted in identifying the *pre-test-post-test non-equivalent control group design* as the appropriate form of experimental design to be used. For these decisions, three main features of the selected design were taken into consideration: first, two intact classes would be needed for the comparative testing and evaluation of the innovative teaching sequence. One would act as the experimental group with the other as the comparison group. The experimental group would be exposed to the research-informed teaching sequence and the comparison group to the traditional normally used instructional method.

Second, random allocation of the students into the experimental and comparison groups would not be feasible in real educational settings. This was particularly true in the case of the proposed research which would be carried out in March-April, that is, close to the end of school year. Students were already allocated into intact classes since the previous June, after they were registered to the first grade of upper secondary school. Also, the fact that the research would take place over the rather long time interval of twelve 45-minute lessons, that is, one half months, would not permit the randomness on a temporary basis.

Third, it would be possible for a pre and a post-test to be administered to both the experimental and the comparison group for the collection of the data required for the first and second research questions. Furthermore, the quasi-experimental approach could facilitate the kind of analysis needed in formulating an answer to the first and second research questions.

As discussed in a previous paragraph, an answer to the third research question should involve a qualitative analysis of the rich set of data collected through pre and post-test, the short-length diagnostic probes and the experimental students' interviews. Qualitative analysis would permit an in-depth investigation and thus for a richer picture of knowledge acquisition of experimental students on the energy concept; in its turn, this could provide further and stronger evidence of the effectiveness of the proposed innovative teaching sequence. Review of research methods in education literature (see, for example: Cohen, Manion and Morrison, 2007; Wilson, 2009) resulted in identifying the *case study approach* as the appropriate one to be used. This decision was based on the fact that, a case study comprises a set of key features which could serve efficiently in reaching to an answer concerning the third research question. First, it allows the intense examination of a particular event such as the testing of an innovative teaching sequence with a small number of participants within a natural context such as real educational settings. Second and, perhaps most important is that, case study is a form of qualitative, descriptive study which enables the collection of detailed data which in turn enables as complete an understanding as possible of the event under study through thick description (Geertz, 1973b); that is, through a process which involves an in-depth description of the event, a process necessary for the evaluation of the teaching sequence tested. In addition, thick description involves interpretation of the descriptive data which enables arriving at conclusions regarding the event being evaluated which in the case of the proposed study would concern the effectiveness of the teaching sequence tested. Third, it permits the use of various different data collection instruments which allow the collection of a rich set of qualitative and also possibly quantitative data to produce adequate evidence which could lead to understanding of the event under question, the testing of the innovative teaching sequence, and to address the research questions. Furthermore, case study has the strength of revealing new perspectives of the event under study for further research. Such perspectives on teaching physics are discussed in Chapter 7.

3.3 OVERVIEW OF THE RESEARCH

Research was conducted in two phases. In the following, these are briefly described.

Phase I: Design and development of the research-informed teaching sequence

In the first phase, the design and development of the research-informed teaching sequence for the instruction of the concept of energy took place. Prior to this, a selection of reports on teaching and learning of the concept of energy in the science education international research literature were critically reviewed and used as a basis for the design. The design and development process of the research-informed teaching sequence is described and discussed in detail in Chapter 4.

Phase II: Experimental intervention and further data collection

In the second phase, the quasi experiment was carried out in three stages as follows:

Stage one

During the first stage, the pre-instructional interpretations about energy of the students participating in the experimental and comparison groups were collected through a pre-test.

Stage two

During the second stage, the experimental intervention and further data collection were conducted. As far as it concerns the intact class acting as the experimental group, the experimental intervention was carried out through the ten-lesson research-informed teaching sequence. Data were collected through the two short-length diagnostic probes which were used as interventions in two of the lessons of the sequence, the two interviews with students, an interview with the experimental teacher and video recordings of the lessons.

Regarding the class acting as the comparison group, the intervention took place with exposure to a six-lesson 'normal' teaching sequence instead of the eight-lesson one defined by the current National Curriculum. At this point it should be noted that 'normal' teaching involves the teacher to introduce the energy ideas through an authoritative approach (Mortimer and Scott, 2003) and following the book. As discussed in the detailed account of the intervention for the comparison group in section 4.11, the teacher restricted the teaching of mechanical working in one half lesson instead of two, as defined by the curriculum, by decreasing the number of worked examples; omitted the introduction of the mechanical working-kinetic energy theorem which usually takes place within half of a lesson and; skipped out the experimental verification of Hooke's law usually carried out by the students within the time of one lesson and introduced it briefly prior to the introduction of the idea of elastic energy.

However, it has to be noted that the ideas which were not introduced and the activities which did not take place are considered as of secondary importance in contributing to understanding of the aspects of energy. Specifically, the experimental treatment of Hooke's law aims to the verification by the students of the proportionality relation between the force exerted on a spring and the deformation produced on it; this proportionality relationship supports the introduction of the idea of elastic energy. The mechanical working-kinetic energy theorem is just an application of the general conservation of energy principle and aims to verify the equity of the amount of energy transferred through a mechanical working pathway and the amount of kinetic energy stored. This issue is discussed in more detail in relation to the results revealed from analysis of post-test data (Chapter 5). Furthermore, data were collected through video recordings of the lessons. This aimed to check whether the experimental and the comparison intervention were conducted according to scheme.

Stage three

During the third stage, the students' interpretations about energy in both the experimental and comparison groups after the intervention were collected through a post-test.

In the following, all three stages of phase II are presented diagrammatically in some detail with two schemas, one for each group. Thus, for the experimental group phase II is presented in Figure 3.1:

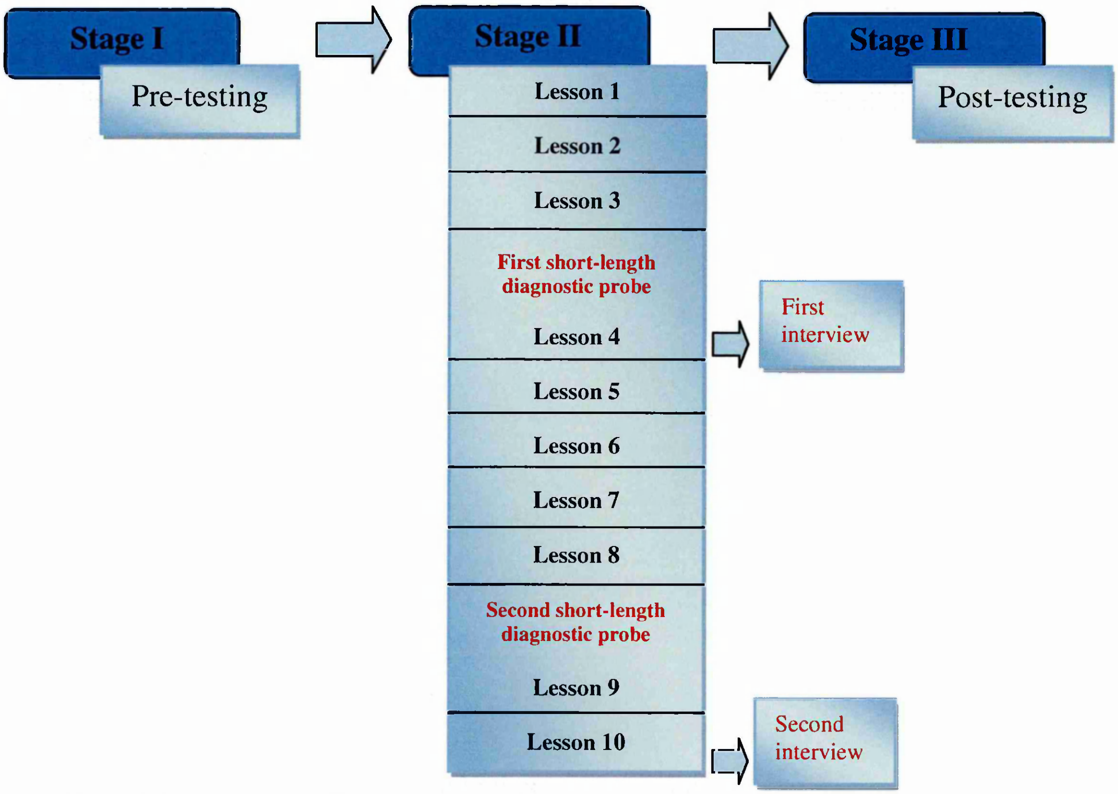


Figure 3.1: Teaching intervention and data collection phase of experimental group.

For the comparison group, phase II is presented in Figure 3.2. The energy knowledge not addressed is illustrated with green letters.

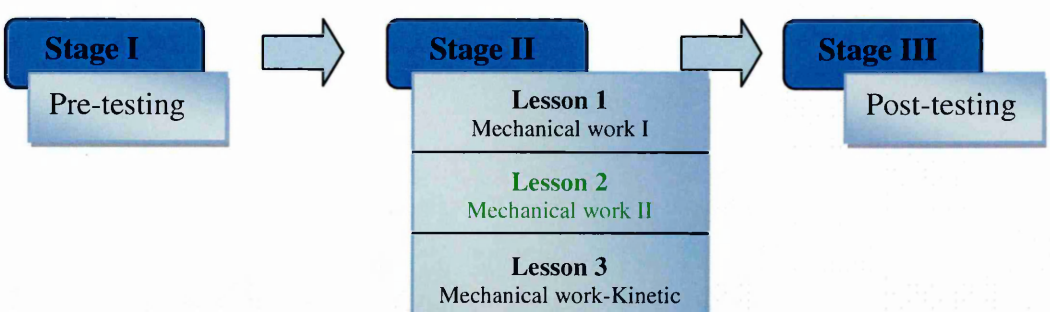


Figure 3.2: Teaching intervention and data collection phase of comparison group.

In the following section, a detailed description of the participants, students and teachers, in the research carried out in this doctoral thesis is presented, as it is defined by the design brief for energy illustrated in Table 4.1 of section 4.2.

3.4 PARTICIPANTS

An urban public upper secondary school in Limassol, Cyprus of which the principal and the staff were open to the idea of educational 'experiments' (the principal used to be a tutor at the Cyprus Pedagogical Institute) was approached for permission to carry out the research. Although there is little significant fluctuation in the educational level of public urban schools, the one selected was among those with a good overall student achievement in the Pan-Cyprian Examinations. Due to the openness of the principal and the staff, the school had a history of being involved in various intellectual, athletic and art competitions and conferences.

The upper secondary school selected is among those with a relatively large number of students. There were eleven mixed ability first grade classes each consisting of 20-24 students aged 15-16 year. Within the Cyprus Educational System, the mixed ability first grade classes are formed with the use of a *stratified random allocation* (Slavin, 1984, p. 23) on achievement in the third and final grade of lower secondary school. Specifically, students who are going to study in the first grade of an upper secondary school, are classified in one of four achievement categories as follows: 'A' for 'excellent' achievement, 'B' for 'very good', 'C' for 'good' and 'D' for 'low' achievement. Then, equal number of students of each category is allocated randomly in classes of mixed ability. Usually, the stratified random allocation produces functionally equivalent groups; but, as Slavin (1984, p. 23) points out: '... there is no guarantee that the groups will in fact be equal on every relevant factor'. Indeed, experience in teaching first grade classes has proved that, in some cases there were small fluctuations regarding the physics overall achievement and also according to colleagues, to that of other subjects between classes. This might be due to the factor of subjectivity in achievement scores given by many different teachers-examiners, gained in the third grade of secondary school, on which the stratified random allocation depends.

Physics lessons in first grade classes took place once a week in a classroom and once a week in one of the two physics laboratories of the school. Each physics laboratory was equipped with a computer, a T.V with a big screen and a video projector. The computer could be connected either to the T.V or the video projector.

The physics teaching team at the school consisted of five full-time teachers and the head teacher. All five teachers were teaching physics between one and three first grade classes. They were keen on testing innovative materials and volunteered to participate in the research. As it is defined by the Cyprus Ministry of Education regulations concerning the appointment of a secondary school teacher, prospective teachers must have two qualifications: a first degree on the subject of teaching and successful completing of the Pre-Service Training Program. Thus, all five teachers were physics specialists and trained educators. Two of the teachers, were colleagues of the researcher in another public upper secondary school of Limassol. After some consideration regarding the way of selecting the teachers who would participate in the research, it was decided that one colleague would act as the experimental group teacher and the other colleague as the comparison group teacher. Although this way of selecting the teachers lacked randomization, it was preferred because of the good working relationship the teachers and the researcher had as colleagues in the past. The matter of who would act as the experimental teacher and who as the comparison one was arranged between the teachers and announced to the researcher. Furthermore, the two colleagues had the same professional characteristics such as a good record in physics teaching, the same experience in teaching first grade classes, IT skilled and the same number of years in service. These could ensure their equivalency in terms of being skilled and experienced and also could ensure their ability in dealing with such instructional materials.

In a meeting of the researcher with the two colleagues, she described in some detail the methodological scheme of the quasi-experiment which would be carried out and explained the role of being the experimental and the comparison teachers respectively. Then, a discussion was conducted concerning the intact classes which would be selected to act as the experimental and the comparison groups. Both teachers proposed that the main criterion for selecting the classes should be the degree of cooperation between the students and the teachers. The two teachers were teaching physics to three first grade classes each and as they stated, a number of students in some classes were less cooperative and thus would be less likely to consent to participation in the research. Their proposition was considered by the researcher as quite justified and was therefore agreed. Each of the teachers proposed one of their classes which they considered as the most cooperative. A series of key features of the classes selected were compared to assess the level of match. First, the average overall student achievement in physics of the classes was compared and found about the same. As comparison measure, the mean value of the students' grades in each class for the first and the second trimester was used. Second, the number of students in each class was compared and also found about the same; in particular, the intact class which would act as the experimental group consisted of twenty students whereas that which would act as the comparison group of twenty two students. Third, the timetable of the classes was compared and found that physics lessons were taking place in different days of the week. Although simultaneous teaching of physics was desirable from a research methodology perspective according to which, an educational 'experiment' should be carried out under the same conditions, this was proved not feasible in the case of the selected classes and in addition, it was not considered as a serious problem.

Of the intact class which acted as the experimental group, eighteen students consented to participate in the research, one did not participate because she moved with her family to another town and another one was excluded as being a student with learning problems who was following an individual educational program. Furthermore, regarding the intact class who acted as the comparison group, eighteen students consented for participating in the research whereas the other four did not consent. Thus, thirty six students participated in the research from which half of them very conveniently acted as the experimental students and the other half as the comparison students.

3.5 DATA COLLECTION

In this section, the rationale and the development process of the data collection instruments used in the research are discussed in detail. Discussion is then turned to the considerations made concerning their reliability and validity.

3.5.1 DATA COLLECTION INSTRUMENTS

Data were collected with the use of two kinds of data collection instruments: written questionnaires and individual interviews. In addition, video recordings of both the experimental and the comparison lessons were made.

Written questionnaires included a pre-test, two short- length diagnostic probes and a post-test. Individual interviews were conducted with a sub-cohort of experimental group students and the experimental teacher. In particular, two individual interviews were conducted with four experimental students and an extensive one, with the experimental teacher.

In the following, the rationale upon which the development of each written questionnaire and interview protocols were based is described and discussed. Also, the aims of video recordings of the experimental and the comparison lessons are presented.

3.5.1.1 WRITTEN QUESTIONNAIRES

i. Pre-test

The pre-test aimed to collect data which would provide information concerning the students' interpretations about energy prior to instruction of the concept. Data collected were used in four ways: first, to draw conclusions which allowed for an answer to the first research question. Second, in a comparative study with the corresponding data collected through post-test to draw conclusions which allowed for an answer to the second research question. Third, they were used for the investigation of the initial conditions of the groups. As discussed in section 3.5, random allocation of the participants in the experimental and the comparison group was not feasible and random allocation on achievement in the intact classes which acted as the experimental and the comparison group could not guarantee their equivalency. However, the comparative study of findings revealed from analysis of pre-test data allowed the determination of whether the two groups were initially equivalent. Fourth, they were combined with those collected through the two short-length diagnostic probes, the two interviews and post-test to set out the energy learning profile of the four experimental students who volunteered to be interviewed. 'Energy learning profile' is referred to the detailed study of the experimental students' developing understanding of the concept of energy taught through the research-informed teaching sequence. These allowed for an answer to the third research question.

For the collection of the students' pre-instructional interpretations about energy, it was decided that a phenomenologically based approach would be used. A 'phenomenological approach' (Driver and Erickson, 1983) involves presenting students with an event or a system and through a set of diagnostic questions be allowed to formulate interpretations about the behavior of the event or the system in terms of their choice. In this way, it is possible for inferences to be made about the interpretations about energy that the students use prior to instruction, based on their past teaching or their experiences. In order to characterize students' interpretations an 'ideographic approach' can be used (Driver and Erickson, 1983) so that the character of students' interpretations is presented. A 'nomothetic approach', in contrast, would judge students' responses against canonical scientific knowledge.

In particular, it was decided that pre-test would consist of two parts: part A would comprise a set of diagnostic questions aiming the collection of data about energy knowledge due to past teaching. Part B would comprise a set of questions aiming the collection of data through which the specific students' pre-instructional interpretations about energy could be detected in the case of little or no energy knowledge acquisition prior to experimental intervention.

In pre-test part A, it was decided that the set of questions would refer to the study of a physical process taking place in a system. Moreover, it was decided that a computer simulation would be created to present the physical process rather than being depicted in an image. In that way, the advantage of motion would be used, as discussed in section 4.9, to present more explicitly the changes observed in the system due to the progression of the physical process in it. This would allow for the investigation of the students' ability in identifying the changes and in formulating a physical description of the process, as the second of four of descriptions defined in the theoretical framework of this study (section 4.7). Also, this would allow for the investigation of the different kinds of the students' initial interpretations for the observed changes in the system with interest being placed on whether they would use energy or any other physical construct.

In selecting the system which would be presented in the simulation it was decided that, this should consist of more than one moving part and the surrounding air and the ground or a horizontal plane would also be part of it. Regarding the physical process which would take place in the system, it should be one in which its start, progression and end be explicitly presented. The decision for selecting a system with the above characteristics was based on the belief that it would allow for the selection of explicit data sets concerning each of four energy aspects rather than selecting a system in which a single object executes a repeated motion. In particular, a physical process with an explicit start would allow for the investigation of the students' ideas on the energy store aspect; its progression with two moving parts would allow the investigation of the students' ideas of the transfer and conservation aspects of energy, and; its ending in a system with surrounding air and the ground or a horizontal plane being parts of it, would allow the investigation of the students' ideas of the conservation and degradation of energy aspects. The understanding of four energy aspects, namely, store, transfer, conservation and degradation, consist key teaching goals which are included in the set of teaching goals identified in the research-informed sequence presented in detail in section 4.10.4.

The system which was finally developed consisted of a compressed spring placed in a horizontal position with a small ball in front of it, lying on a horizontal plane. As the spring stretches, it sets the ball into a decelerated motion on the horizontal plane where it finally stops. Three snapshots of the start, progression and end of the physical process are illustrated in Figure 3.3. Furthermore, model responses to the diagnostic questions referred to the process of the system of the simulation are provided in Appendix G.

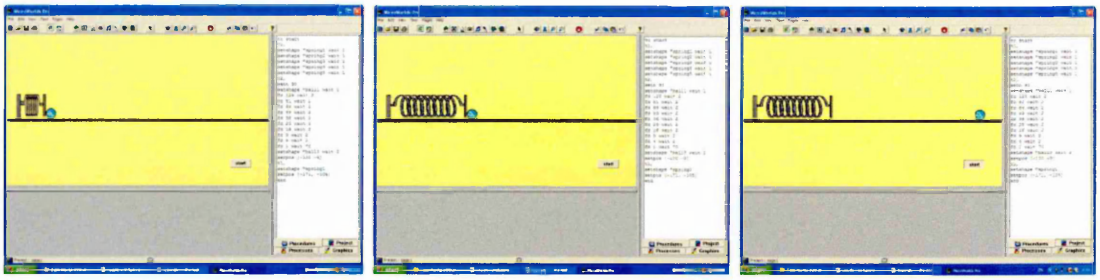


Figure 3.3: Snapshots of the process which takes place in the simulation.

Another issue which was taken into consideration concerned the kind of questions to be used and the language in which these would be formulated. It was decided that since a phenomenological approach would be used, qualitative open-ended questions would be the most appropriate since they would allow the possibility for students to express their ideas in extended terms, something desirable in terms of collecting a rich set of data. Furthermore, it was decided that the questions should be formulated in an as simple as possible language in which terminology related to the energy concept would be avoided.

Regarding pre-test part B, it was decided that a different structure to that of part A would be more appropriate for the collection of the students' pre-instructional interpretations about energy. Specifically, it was decided that this should comprise of a set of images on which the students would be asked to state whether there is energy and to briefly justify their response. Taking into account the students' alternative models reported in the international science education literature discussed in Chapter 2, ten simple systems were developed. In a further consideration, six of them were selected as the most appropriate since ten was considered as too large number and in addition, the four excluded could provide similar sets of data to others included. The six systems which were finally selected are: a moving car, a battery, a runner, a book on a self, a barrel of petrol and, a stretched elastic band. Model responses corresponded to each of these systems are provided in Appendix G. Furthermore, possible students' non-scientifically based responses could reveal the specific alternative models (Chapter 2) held by them.

The final version of pre-test was translated into Greek and administered to students of both the experimental and the comparison group. This is illustrated in English in Appendix A.

ii. Post-test

The post-test aimed to collect data which would provide information concerning the students' interpretations about energy after the teaching interventions. Taking into consideration the second and third research questions it was decided that, the post-test would consist of two parts: part A would be the same as the corresponding part A of pre-test. It would aim to reveal the extent of the students' ability in identifying the changes observed in the system of the simulation and in formulating a physical description of the process taking place in it, the different kinds of the students' interpretations for the observed changes in the system and their conceptions concerning each of four energy aspects after the experimental intervention. These teaching goals are presented in detail in section 4.10.4.

For part B, it was decided that a conceptually based approach should be used. A 'conceptual approach' (Driver and Erickson, 1983) involves students be presented with words or concepts and be asked to perform specific tasks with them. In that way, inferences about students' understanding about these words or concepts could be made. In particular, it was decided that students would be presented with two novel physical systems and be asked to respond to two sets of diagnostic questions on the energy ideas introduced through the teaching interventions, one for each system. The sets would include both qualitative and quantitative diagnostic questions. Furthermore, it was decided that for the analysis of the students' responses a nomothetically based approach should be used. A 'nomothetic approach' (Driver and Erickson, 1983) involves evaluation of the responses in terms of the current scientific beliefs for a topic or a particular theory of learning. This would allow the establishment of comparisons between the groups and furthermore, the formulation of an answer to the second research question.

Focusing on the content of part B it was decided, as already discussed above, that this would comprise of both qualitative and quantitative questions which would refer to two different physical systems illustrated in two images. Qualitative questions would allow for the investigation of the students' views of each of four energy aspects whereas quantitative questions focused on their ability at quantifying the energy ideas. In addition, qualitative questions would take an open-ended form so as to allow for the students to express their interpretations about energy. Data collected would allow for the investigation of the extent of the students' ability in transferring the acquired knowledge on energy both qualitatively and quantitatively to novel physical systems.

In selecting the systems which would be illustrated in the images, it was decided that one would involve a process which progressed in a horizontal direction and be different from that presented in the simulation, and the other a process which would take place in a vertical direction. In that way, all three systems would be different and different energy stores/forms of energy and energy transfer pathways/transfers from those taught would be involved. Furthermore, it was decided that the ground or a horizontal plane and/or the surrounding air would be part(s) of the systems. Also, images should explicitly illustrate the start, progression and end of the process taking place in the systems between two snapshots of it. This would allow for the collection of explicit sets of data concerning the store, transfer, conservation and degradation aspects of energy.

The first system which was developed to be included in the post-test part B consisted of a car travelling along a straight horizontal road with constant speed. At a point A, the car runs out of petrol and its engine stops working. The car decelerates and finally stops at a point B. The second system consisted of a boy who throws a coin up into the air. The coin moves up through the air, and reaches a maximum height before falling. In both systems, all data necessary for the quantitative questions are provided.

Data collected from post-test part A and B were used in three ways: first in a comparative study with those collected through pre-test to draw conclusions which allowed for an answer to the second research question. Second, experimental group part A data were compared with those of part B to draw conclusions concerning the experimental students' ability in transferring the acquired knowledge on the energy concept to novel physical systems. Third, data concerning the four experimental students interviewed were combined with those drawn from pre-test, short-length diagnostic probes and individual interviews to set out each student's energy learning profile (section 3.5.1.1) which allowed for an answer to the third research question.

The final version was translated in Greek and administered to the students of both the experimental and the comparison group. The final version in English is illustrated in Appendix B.

iii. Short-length diagnostic probes

Short-length diagnostic probes were designed to monitor the four interview volunteers from the experimental group students' development in understanding of the energy concept taught through the research-informed teaching sequence. However, for practical reasons and in order the four students' school timetable be disturbed to a minimum degree, it was decided that the diagnostic probes be administered to all of the experimental class. For the rest of the experimental students, these would act as further exercise about the energy ideas. Taking into account that, due to limited school time the experimental intervention should not exceed twelve lessons, it was decided that two 15-20 minute diagnostic probes could serve this goal. Furthermore, it was decided that the first diagnostic probe be administered after the first three lessons of the teaching sequence, when all energy ideas and the new terminology would be introduced. Whereas the second would be used, after the eighth lesson, when both the more detailed qualitative and quantitative treatments of the energy ideas would be complete.

In considering the content and structure of the two diagnostic probes it was decided that, these would comprise of a set of questions which would refer to a physical system illustrated in an image. In selecting the systems which would be included in the diagnostic probes, it was decided that these would have the same characteristics as those presented in the simulation and the post-test part B respectively.

The first diagnostic probe would comprise of a set of qualitative, open-ended questions. These would target firstly the experimental students' ability in describing the physical process taking place in the system of the image in terms of energy, both verbally and diagrammatically, through a Full Sequence Energy Diagram and, secondly the students' understanding of each of four energy aspects introduced.

The system to be included in the first diagnostic probe consisted of a skier starting sliding from a point A on a smooth mountain slope down to a snow covered horizontal plane which is smooth up to a point B. The skier finally stops at a point C after he covers distance BC where the snow is rough.

The final version of the first diagnostic probe was translated into Greek and administered to experimental students in the first 15 minutes of the fourth lesson of the teaching sequence. This is illustrated in English in Appendix C.

The second diagnostic probe also comprised of a set of qualitative, open-ended questions. Again, questions targeted the experimental students' ability in describing the physical process taking place in the system in the image verbally and diagrammatically, but using a Sankey diagram this time.

The system included in the second diagnostic probe consisted of a worker about to lift a box up to the first floor of a building. To do so, the worker has the choice to use one of three methods: (a) pushing the box on a smooth inclined plane, (b) using the stairs or, (c) using a frictionless pulley.

The final version of the second diagnostic probe was translated into Greek and administered to the experimental students in the first 20 minutes of the ninth lesson of the teaching sequence. This is illustrated in English in Appendix D.

Data collected from the two diagnostic probes were combined with those collected from the individual interviews with the experimental students, their pre-test and post-test to set out the students' energy learning profiles (section 3.5.1.1). From these, conclusions were drawn to provide an answer to the third research question.

3.5.1.2 INDIVIDUAL INTERVIEWS

i. Students interviews

Interviews with the four experimental students aimed to collect data which would provide deeper and more detailed insights concerning the students' understanding of the energy ideas taught through the research-informed teaching sequence. Having in mind the order and the content of each lesson of the teaching sequence, it was decided that two interviews would be conducted; one after the first three lessons in which all the energy ideas and the new terminology are introduced and the other on the completion of the experimental intervention.

Taking into consideration the aims of the interviews, it was decided that these should take a semi-structured form (see, for example: Wilkinson and Birmingham, 2003, p. 45). The decision about the appropriateness of conducting semi-structured interviews was based on two key features: first that they allow for the researcher to explore the topic of interest and to control the direction of the interview to a good degree. Second that, they allow for the researcher to probe responses given by the responder and also ask for clarification for others. Furthermore, it was decided that open-ended questions (see, for example: Anderson, 1988, p. 184) would be suitable for the key questions to be included in the interview protocol.

Another issue which was carefully considered concerned the kind of interviews to be conducted. Again, taking into account the interview aims, it was decided that these should be individual rather than group interviews, although the latter would be timesaving. In this decision, the students' overall achievement in physics and their background were taken into consideration. Specifically, two of the students were high achievers whereas the other two were low achievers. In addition, one of the high achievers had previous knowledge of the energy concept acquired from GCSE afternoon classes in Physics. It was believed, these backgrounds would not ensure an individual response from all four students to each key question of the interview protocol in a group setting; rather, high achievers would respond both on their and the low achievers behalf. Moreover, group interviews would not allow for the researcher to address, where probing or clarification was needed, a series of follow-up questions to one specific member of the group. In addition, interviews would be audio and not video recorded and thus, this would put a difficulty in coding up the responses of each member of the group (see, for example: Cohen, Manion and Morrison, 2007, p. 287-88).

Much thought was given to the way in which the energy ideas would be probed in the individual interviews. It was decided that, the set of key questions in each of the interview protocols refer to a physical process taking place in a system illustrated in an image. The key questions would be grouped in one of three thematic sub-sets: in the first, those which probe the students' ability in describing the physical process in terms of energy would be included. These, would be supported by two Full Sequence Energy Diagrams. The first would represent the energy description of the physical process taking into account the degradation procedure. By contrast, the second focuses on the energy description of the process under ideal conditions, when no energy transfers along a heating pathway take place. In the second thematic sub-set, the key questions probe the students' understanding of the energy ideas introduced. In particular, these would refer to all four energy aspects of store, transfer, conservation and degradation. Finally, in the third thematic sub-set, the key questions probe the students' understanding of the nature and the role of energy in science.

The system selected for the first interview, consisted of a curved metallic rail on which a small glass marble is let go from its highest points to roll on. The system for the second interview consisted of a golf player who hits a golf ball on a horizontal grass ground. The ball is set in a decelerated motion and finally stops at a distance away from the golf player. The image of the system, the two Full Sequence Energy Diagrams and the interview protocol for each of the interviews are illustrated in Appendixes E and F respectively.

Data collected from individual interviews with experimental students were combined with those collected from pre-test, post-test and diagnostic probes to set out the students' energy learning profiles (section 3.5.1.1). In setting up the energy learning profiles it was decided that ideographic analysis should be used since these aimed to probe the development of understanding of the concept of energy. From these, conclusions were drawn to provide an answer to the third research question.

ii. Teacher interviews

The interview with the experimental teacher aimed to collect the teacher's views concerning the effectiveness of the research-informed teaching sequence mainly in promoting conceptual understanding of the energy concept and then, be enjoyable to students and easy to teach for the teacher. Although considerations in the designing phase of the quasi experiment advocated for short-length interviews conducted after the end of each lesson, this proved to be practically impossible without causing much inconvenience to the teacher in following her school timetable. In a friendly discussion the researcher had with the teacher, it was decided that an extensive interview would be conducted on the completion of the experimental intervention. For that purpose, the teacher would keep notes in her own time about each lesson, to be used in the interview.

Taking into account the aim of the interview, it was decided that this would be a semi-structured one and the interview protocol comprised of a set of open-ended key questions. The key questions were grouped in two sub-sets. In the first, the questions were aimed at the detailed probing of each lesson of the teaching sequence. Specifically, these would concern the content in terms of energy ideas, the means used for introducing the energy ideas, the kind of classroom talk used and the estimated time for each activity to take place. In the second sub-set, questions were aimed at the overall evaluation of the teaching sequence. These would include the number of lessons in the teaching sequence, its structure and the order in which the energy ideas are introduced.

Data collected were used for a review of the overall strengths and weaknesses of the research-informed teaching sequence in a discussion conducted on these issues in Chapter 7.

3.5.1.3 VIDEO RECORDINGS

Video recordings were aimed to monitor the extent to which the experimental and the comparison lessons were performed according to their design. Specifically, as far as it concerns the experimental lessons, video recordings would allow the investigation of whether the research-informed teaching sequence was completed by the teacher, whether the content of each lesson was taught, the means planned to be used for the introduction of the energy ideas were used and the defined as appropriate classes of communicative approach were applied. Regarding the comparison lessons, video recordings would allow the investigation of whether the number of lessons defined by the Cyprus National Curriculum for Physics was completed by the teacher, whether the content on energy defined by the curriculum for each lesson was taught and also, whether the teacher would be used any kind of means for the introduction of the energy ideas.

Data collected were used to draw conclusions which contributed to an answer to the second research question.

3.5.2 RELIABILITY AND VALIDITY OF THE DATA COLLECTION INSTRUMENTS

The written questionnaires and the two interview protocols used in interviewing the four experimental students were reviewed by three expert reviewers. Each expert reviewer holds a first degree in physics, a doctoral degree in science education and is active researcher in physics education. In a meeting, the researcher briefly outlined the rationale underlined the data collection instruments. Then, she asked the three experts to comment on the extent of the appropriateness and the consistency of the tasks included in them with respect to the outlined rationale. Furthermore, the three experts were particularly encouraged to suggest possible changes concerning the physical systems included the structure of the instruments and the formulation of the tasks in them. The expert reviewers agreed on the validity of the rationale underlying the data collection instruments and the targeting between the tasks and the energy idea they were intended to investigate. In addition, they commented on the structure of the instruments and the formulation of the tasks in them. This review procedure provided an indication of the content validity of the data collection instruments (see, for example: Cohen, Manion and Morisson, 2007). Following this, the instruments were given to two experienced first grade high school physics teachers, other than those who acted as the experimental and comparison teachers. Each of them was asked to comment on the formulation of the tasks included in the instruments with respect to this students' age group. The feedback gained by the reviews of the three experts and the two physics teachers was used by the researcher to proceed to some amendments concerning the number, the formulation and the order of the tasks included in the data collection instruments.

The revised version of the pre-test was pilot-tested with one first grade high school class consisting of twenty students in which one of the physics teacher reviewers was teaching. Observations made by the researcher concerning the students' attitude to the simulation and the tasks included in the pre-test as well as the study of their responses in each task provided empirical evidence for the appropriateness of all data collection instruments since their development was based on a similar rationale and similar wording was used. Moreover, no indication of serious misunderstanding of any of the tasks emerged and the data collection instruments underwent minor further amendments.

3.6 DATA ANALYSIS

This section includes a detailed description and discussion of the analysis approaches followed in analyzing the data collected through each of the data collection instruments used in the research.

3.6.1 WRITTEN QUESTIONNAIRES

i. Pre-test questionnaires

After numbering the pre-tests of each the experimental and the comparison group from 1 to 18, a coding scheme for pre-test part A and part B was developed (see, Appendix G). The analysis procedure started with data collected through pre-test part A. This aimed to reveal on one hand the different kinds of interpretations the students formulated for the event of the simulation and on the other hand, the students' views on each of four aspects of the energy concept prior to formal instruction. Furthermore, the analysis sought to lead to findings which would allow determination of whether the two groups were initially equivalent.

For all five questions of pre-test part A, a broadly ideographic approach analysis was followed. This included two stages: in the first stage, responses given by each experimental and comparison student to each individual question were studied carefully and the various different kinds of responses were identified. These were then used for the formulation of sets of coding categories which were describing the qualitatively different ways in which the students responded to the tasks of each individual question. The coding categories revealed were refined over and over until a final satisfactory form was reached. Subsequently, each set of coding categories was inserted in individual comparison tables with corresponding typical students' responses and frequency results.

In the second stage, coding categories in each set were studied and subjected to further classification using the coding scheme aimed to outcomes which would lead to the pursued kinds of findings. Each set of coding categories was inserted in individual comparative tables with frequency and percentage results and presented diagrammatically in frequency-coding category bar charts in two ways: presenting the total number of participant students in each coding category and the number of students in the experimental and the comparison group in comparison in each coding category.

The study of the first kind of bar charts led to conclusions concerning the students' initial interpretations of the event of the simulation and their initial views on each of four energy aspects of the energy concept for the total of participant students. Furthermore, the study of the second kind of bar charts led to comparative conclusions and thus identified, whether the intact classes acting as the experimental and the comparison group were initially equivalent.

Results presented in the second kind of bar charts were subjected to statistical analysis to test whether or not there was initially a statistical significance association between the experimental and the comparison group. The statistical test selected was suitable for testing the significance of association between categorical data as those revealed from the ideographic analysis described earlier. Review of the research methodology literature resulted in focusing on the chi-square test (see, for example: Field, 2009) which though, proved to be inapplicable since it is suitable for large sample sizes and also, when the frequencies in any of the cells of the association table are over 5 (for two degrees of freedom), prerequisites which were not fulfilled either by the number of participant students or the frequency results in every table. Further review of the research methods literature resulted in selecting the Fisher's Exact Test (see, for example: Field, 2009) as the most suitable since it is a statistical significance test used in the analysis of association in the case of small sample sizes. However, a difficulty arose in the application of Fisher's Exact Test since its use involves a 2 x 2 association table. Association tables constructed in the second stage of the ideographic analysis were 2 x n tables, that is, comprised of the two groups, the experimental and the comparison and, a number of coding categories. After some consideration, it was decided that this difficulty could be overcome by collapsing the coding categories and creating two broader ones, the: 'Correct response' and the 'Any other response'. Data inserted in the 2 x 2 association tables were elaborated in the PASW Statistics 18 program and p values were calculated. Results were illustrated in tables provided by the program.

In determining whether there is a significance association or not between two objects being compared, the significance of deviation from the null hypothesis, that is, there is no association, is examined. In the case of Fisher's Exact Test, the null hypothesis is expressed by the $p_{cutedge}=0.05$ value. Thus, for $p_{value} < p_{cutedge}$, the null hypothesis is rejected, that is, there is a significant difference between the two objects being compared. Otherwise, for $p_{value} > p_{cutedge}$, no significant difference exists between the objects being compared. Furthermore, the significance association of the experimental and comparison students' initial interpretations for the event of the simulation and their conceptions on each of four energy aspects were examined with comparing the p values calculated with $p_{cutedge}$ of the test.

Turning to pre-test part B data, the analysis aimed to reveal the students' alternative interpretations about the energy concept. For all six systems used in the pre-test part B, ideographic analysis was also followed. Responses given by the experimental and the comparison students concerning whether there is energy in each system were studied carefully with attention being placed on the reasoning through which the responses were justified. In a preliminary categorization, responses to each of the six systems were classified in three broad provisional categories: to those justified through correct scientifically reasoning, to those justified through an alternative reasoning and to those which were not justified. For the classification of the responses in the first provisional category, the coding scheme (see, Appendix G) was used. Further careful study of the sets of responses corresponding to each of the six systems and which were classified in the second provisional category revealed that, the energy ideas being expressed by the students could be classified in one of the alternative energy models discussed in some detail in Chapter 2. After some consideration, it was decided that the seven alternative energy models: 'anthropocentric', 'depository', 'ingredient', 'activity', 'product', 'functional' and 'flow-transfer' (see, for example: Gilbert and Pope, 1986) constituted coding categories of the scheme which would be used for the final analysis. Furthermore, it was decided that the responses which were preliminary classified in the first provisional category be classified in the coding category: 'Correct energy model'. Those classified in the third provisional category were now coded as, 'No implicit model'. The coding scheme developed and used for each of the six sets of responses is illustrated in Appendix H.

The coding categories devised for each of the six systems were tabulated with examples of typical students' responses and frequency results. As in the case of pre-test part A results, frequency-coding category bar charts were created that presented the total number of participant students as well as the number of students in the experimental and the comparison group in comparison for each coding category.

The study of the first kind of bar charts allowed conclusions to be drawn concerning the alternative interpretations about energy used by students prior to formal instruction of the concept. Furthermore, the study of the second kind of bar charts led to comparative conclusions and thus, allowed to determine, along with the corresponding drawn from pre-test data analysis, whether the intact classes acted as the experimental and the comparison group were initially equivalent.

ii. Post-test questionnaires

Post-tests of the experimental and the comparison group were numbered from 1 to 18 with the same number to correspond to the same student in both the pre and the post-test. Due to the fact that the experimental and the comparison group were exposed to different teaching approaches for the instruction of the energy concept during the intervention, data collected through the post-test could not be analyzed using a common coding scheme. For that reason, a coding scheme (see, Appendix I) in which the research-informed materials and another one (see, Appendix J) in which the current physics curriculum was taken into account were developed. However, it has to be noted that, the two coding schemes were developed in such way that their use led to similar coding categories to those revealed with the use of coding scheme developed for the analysis of pre-test part A data. This was important in allowing for comparison measurements between pre and post-test findings in relation to the second research question. The analysis procedure started with data collected through post-test part A. This aimed to reveal the students' ability in interpreting in terms of energy the event of the simulation and on their views concerning each of four aspects of energy after the experimental intervention.

Post-test part A data were elaborated following the same two-stage approach followed for the analysis of pre-test part A data. Likewise, coding categories revealed from the first stage analysis were inserted in individual comparative tables for each question with corresponding typical students' responses and frequency results. Furthermore, coding categories revealed in the second stage analysis with the use of the two corresponding to each teaching approach coding schemes were inserted in individual comparative tables with frequency and percentage results. These, were also presented diagrammatically in frequency-coding category bar charts in two ways: first, presenting the total number of students in each coding category and second, the number of students in each group in comparison for each coding category. Moreover, as in the case of the corresponding pre-test comparative bar charts, findings illustrated in them were subjected to statistical analysis using the Fisher's Exact Test aimed to investigate the significance association of the experimental and comparison students' ability in formulating an energy interpretation for the event of the simulation and on their views on each of four energy aspects. Results from statistical analysis are also illustrated in tables provided by the PASW Statistics 18 program.

Turning to post-test part B data, the analysis aimed to reveal the students' ability in transferring the acquired knowledge on energy to two novel systems. Data included both qualitative and quantitative forms, collected through the qualitative and the quantitative questions respectively in the sets of questions referring to each of the two novel physical systems. The qualitative data were elaborated following the two-stage analysis procedure followed for the analysis of pre and post-test part A data. Again, coding categories revealed from the first stage analysis were inserted in individual comparative tables with corresponding typical students' responses and frequency results. Also, coding categories revealed from the second stage analysis were inserted in individual comparative tables with frequency and percentage results and presented diagrammatically in frequency-coding category bar charts only for the number of students in each group in comparison for each coding category. The study of the bar charts led to conclusions concerning the students' ability in transferring the acquired knowledge on the energy ideas qualitatively to the two different physical systems of post-test part B.

Regarding the analysis of the quantitative questions, these were subjected to a broadly nomothetic approach to analysis as follows. Responses given by the students to the quantitative questions were studied carefully and classified in two broad categories: 'Correct result' and 'Incorrect result', according to the result reached after mathematical elaboration. Responses classified in each of these categories were further studied with attention being placed on whether the reasoning used was correct or incorrect, that is for example, whether the conservation of mechanical store principle or the kinetic store-mechanical working theorem were identified and used, and how this was used for the correct or incorrect result to be reached. This approach led to four coding categories: 'Correct result-Correct reasoning', 'Correct result-Incorrect reasoning', 'Incorrect result-Correct reasoning' and, 'Incorrect result-Incorrect reasoning'. The coding scheme used for the elaboration of quantitative data is illustrated in the diagram of Figure 3.4.

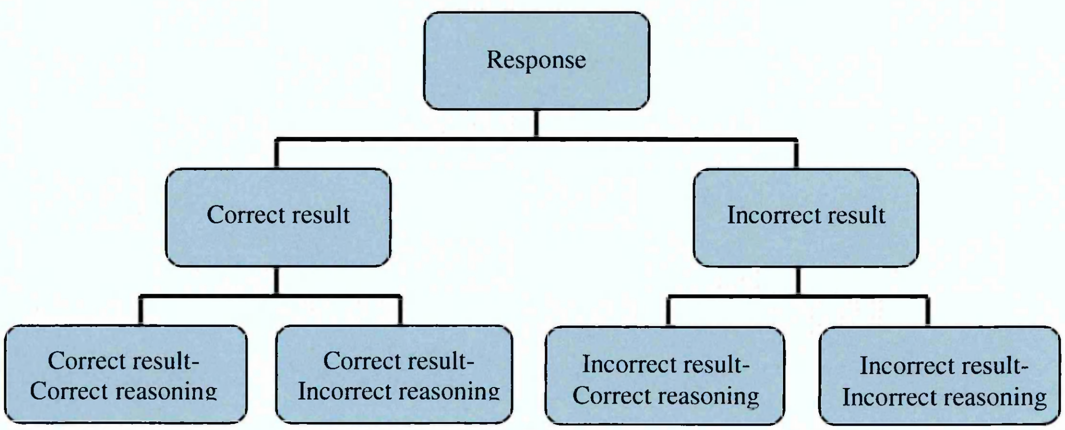


Figure 3.4: Coding scheme of post-test part B quantitative questions.

Coding categories revealed for each quantitative question were inserted in individual comparison tables with corresponding typical students' responses and frequency results. Also, they were presented in frequency-coding category bar charts in which the number of experimental students was compared with that of comparison students for each coding category. The study of the bar charts allowed conclusions to be drawn concerning the students' ability in transferring the acquired knowledge of the energy ideas quantitatively to the two different physical systems included in post-test part B.

Another kind of analysis performed, involved the comparison of the results revealed from the elaboration of experimental students' post-test part A and B data. This was across questions examining the students' understanding on each of four energy aspects. Specifically, the similar coding categories revealed for each question and the frequency results corresponding to each of the three physical systems in the post-test for each of four energy aspects were inserted in individual comparison tables. These, were presented in frequency-system bar charts in which the number of students in each group who acquired an understanding of each of four energy aspects in each physical system was compared. The study of the bar charts allowed for conclusions concerning the experimental students' understanding of four energy aspects and their ability in transferring the acquired knowledge on energy to different physical systems.

iii. Short-length diagnostic probes

The two diagnostic probes of each of four experimental students were initially translated into English. Analysis of data collected through the two diagnostic probes aimed to provide insights concerning the experimental students' development of understanding of the energy ideas introduced in the course of the experimental intervention. For the analysis of data collected, the same approach was followed and a coding scheme for each diagnostic probe was developed (see, Appendixes K and L). In particular, the students' responses to each question were studied carefully and analyzed with the use of the appropriate coding scheme. Then these were commented upon according to the extent of the students' understanding on the energy idea being probed.

The actual responses of the students and their commentary on the questions of each diagnostic probe consisted separate parts of each student's energy learning profile document (section 3.3.1.1), along with those of the pre-test, post-test and individual interviews.

3.6.2 INDIVIDUAL INTERVIEWS

i. Students

Each of four interviews consisting of two meetings with the four experimental students was transcribed from the audio recorder memory into individual written records in Greek and then translated into English. Analysis of data collected through the two sets of interviews aimed to provide deeper insights concerning the experimental students' understanding of the energy ideas taught through the research-informed teaching sequence. For the analysis of data collected through interviews, the same approach was followed and a coding scheme for each set was developed (see, Appendixes M and N). The students' responses to each question of the interview protocols were studied carefully and from these, quotations revealing the students' understanding of the energy idea being probed by each question were collected. Each quotation was analyzed with the use of the appropriate coding scheme and commented on the grounds of the extent of the students' understanding on the energy idea being probed.

On the completion of the analysis procedure, a written document was developed for each interview. The two written interview documents corresponding to each of four experimental students was used, in combination with those developed in the pre-test, post-test and short-length diagnostic probes analysis, to set up each students' energy learning profile (section 3.5.1.1).

ii. Teacher

As in the case of the students' individual interviews, the interview conducted with the experimental teacher was initially transcribed from the audio recorder memory into a written record in Greek and then translated into English. Analysis of the data collected through the interview aimed to provide more detailed insights concerning the effectiveness of the research-informed teaching sequence, as this was implemented and experienced with teaching by the teacher. A careful study of the interview revealed much data included in it. Having that in mind, it was decided that this rich data would be best elaborated by being exposed to a thematic analysis, based on emerging issues from reflection on the whole teaching sequence, rather than a lesson by lesson analysis for each of the ten lessons of the sequence. After some consideration, it was decided that thematic analysis would involve the selection of those ideas which would concern the teacher's views on the strengths and weaknesses of the teaching material, the students' attitudes towards the 'new' approach and the impact on their learning, on her teaching of specific issues as well as an overall evaluation of the research-informed teaching sequence. For each theme, quotations of the teacher's views were selected to be analyzed and commented upon. On the completion of each theme, a written interview document was developed.

Data included in the document was used for a review of the overall strengths and weaknesses of the proposed within this doctoral thesis research-informed teaching sequence in the discussion Chapter 7.

3.6.3 VIDEO RECORDINGS

In order for the data collected through the video recordings of both the experimental and the comparison lessons to be analyzed, a rubric was developed and used. This included three parts: the first part concerned the content of each individual lesson, the second the instructional means used and the third part, the kind of classroom talk applied. The rubric used for the analysis of video recordings of each lesson is illustrated in Table 3.1.

Table 3.1: Rubric for the analysis of video recorded lessons

LESSON ...			
Part	**Issue**	**Yes**	**No**
Content	• Specific issue • ... •		
Instructional means	• Specific mean • ... •		
Kind of classroom talk	• Specific kind of classroom talk • ... •		

As far as it concerns the experimental lessons: the first part aimed to check whether the specific issues included in each lesson of the research-informed teaching sequence were taught; the second aimed to check whether and how the instructional means included were used and; the third part aimed to check whether and how the defined as appropriate class of communicative approach was applied.

Regarding the comparison lessons: the first part aimed to check whether the specific issues in each individual lesson, as defined in the current physics curriculum, were taught; the second aimed to check what kind of instructional means were used and; the third part aimed to check whether 'normal' directive teaching or any other kind of classroom talk was used.

Data collected was combined with those collected from pre and post-test for an answer to the second research question.

3.7 ETHICAL CONSIDERATIONS

The study was conducted in accordance with the British Educational Research Association ethical guidelines at all stages. About three months prior to the estimated start date of the instruction of energy in the first grade of public upper secondary schools, the Cyprus Ministry of Education and Culture was sent a letter requesting permission to carry out the research in an urban school of Limassol. In replying, the researcher was informed that, in order for the Ministry of Education to grant permission in carrying out an educational experiment in a public school, a standard procedure should be followed. This involved first, the principal and the physics teachers of the school of interest being contacted and asked to consent. Then, an electronic application form on the Educational Research Department website was filled in and submitted.

In the first section of the application form, the title of the research, the names of the researcher, her supervisors, the school, principal and the teachers who would participate were required. In the second section, the purpose and a brief description of the research were required. Emphasis was placed on the data collection instruments and the data analysis methods which would be used. In the third section, the ethical issues which might arise and the ethical codes which would be applied by the researcher was required to be discussed. In the fourth and last section, an estimation of the time of completion of the doctoral thesis was required; in the same section, a declaration statement that findings would be announced to the Educational Research Department should be signed.

After the application form was examined, the Educational Research Department send an evaluation report to the Ministry of Education recommending approval of the request. In its turn, the Ministry of Education informed the researcher about its decision to consent the research be carried out in the school selected. Furthermore, a copy of the evaluation report was included and a notice that all ethical issues should be treated as these was discussed.

Two weeks prior to the start date of the research in school, two similar written consent forms for participating in the research were produced by the researcher. One was addressed to the students in the intact class acting as the experimental group and their parents or guardians and the other to those in the intact class acting as the comparison group.

In the written consent forms, the students and their parents or guardians were first informed about the title, the purpose and the significance of the research and the names of the researcher and her supervisors. These were followed by a very brief description of the experimental intervention for teaching the energy concept and the data collection instruments which would be used in each group. Then, they were informed that the lessons would be video recorded and that the video camera would be placed at the back of the classroom. Furthermore, they were informed that their participation was optional, that anonymity would be kept and that findings would be used only for the aims of the research. At the end, they were informed that consent for the research be carried out in their school was reserved by both the Ministry of Education and the principal of the school.

Among the twenty students in the intact class which acted as the experimental group, eighteen of them and their parents consented to participate in the research, one left the school because she moved with her family to another town whereas another one was excluded because she was following an individual educational program due to learning difficulties. In the case of the intact class which acted as the comparison group, eighteen out of twenty two students consented to participate in the research. Moreover, the four students who did not consent to participate asked to be seated at a position in the classroom which would not be within the main frame of the video camera.

Concerning the ethical issues taken into consideration, first it was decided that the research would be carried out in March-April, when energy is taught in the first grade. Thus, no disturbance in the physics education scheme of the participant classes would be caused. Second, as outlined earlier, two intact classes would act as the experimental and the comparison group since random allocation of the participant students was not feasible. Students are allocated in classes and school timetable is constructed long before the start of the school year in September. Furthermore, teachers are appointed at the start of September to teach in certain classes, also following a fixed timetable. Third, it was decided that the content of the current curriculum concerning energy be taken into consideration in the development of the research-informed teaching sequence. This decision was based on the fact that, students in the intact class which would act as the experimental group would be examined on the same final examination paper with students in all other classes taught through ‘normal’ teaching. In that way, experimental students would be equally able to respond to the questions included in the paper concerning energy. Fourth, according to the current curriculum energy is taught within the time of eight 45-minute lessons plus one for the administration of an assessment test. Having this in mind and the school time limitations, it was decided that the instruction of the research-informed materials take place in the time of ten 45-minute lessons plus two for the administration of the pre and post-tests. Fifth, the participant students’ identity was kept confidential in presenting the findings revealed from analysis of data collected through the pre and post-test. As was discussed above, pre and post-tests of both the experimental and the comparison group were numbered from 1 to 18. In presenting the results in each coding category in the comparative tables, no names of the students were inserted.

Ethical codes were also applied in interviewing the four experimental students who volunteered to be interviewed. In each interview, the same procedure was followed. In the opening phase, the researcher first informed the responder that interview would take about ten minutes. Then, she informed the responder that the interview sought to investigate their understanding of physics and that no questions concerning personal issues would be addressed. She avoided specifying that the interview would be focused on their understanding of energy because their ability in interpreting the changes observed in a physical system in terms of energy was one of the issues under study. The researcher further explained that questions would be referred to the physical process taking place in the system of the image which she would show them and informed them that they had the right not to respond to specific questions. Then, she informed the responder that anonymity would be kept in the analysis of data collected through interviews and in presenting the findings. In the following, she informed them that should like to audio record their responses and asked for permission in using an audio recorder. At the end of the interview, the researcher thanked the responder.

3.8 SUMMARY

RESEARCH QUESTION	DATA COLLECTION TOOL	MODE OF ANALYSIS
RQ1.What are the conceptions of a cohort of upper high school Cypriot students prior to teaching about the concept of energy?	**A qualitative pre-test.** - Part A. - Part B.	- Students' responses to each question of part A were analyzed by applying a two-stage analysis approach. In the first stage, responses to each individual question were studied and the various different quotes were identified. These were used for the formulation of sets of coding categories which were describing the qualitative different ways in which the students responded to the tasks of each individual question. In the second stage, coding categories comprised in each set were studied and subjected to further classification using an appropriate coding scheme. - Students' responses to each question of part B were studied and classified according to the reasoning used. For the classification, the seven 'everyday' conceptual energy models presented in detail in Chapter 2 were used as coding categories. - Furthermore, a comparative study of the experimental students' results to each of two parts to the comparison group corresponding results was carried out.
RQ2. How do the conceptions and learning of the sub-cohort of Cypriot students taught through the research-informed approach compare with those following 'normal teaching' after instruction?	**A qualitative pre-test.** - Part A.	-Students' responses to each question of part A were analyzed by applying a two-stage analysis approach. In the first stage, responses to each individual question were studied and the various different quotes were identified. These were used for the formulation of sets of coding categories which were describing the qualitative different ways in which the students responded to the tasks of each individual

		question. In the second stage, coding categories comprised in each set were studied and subjected to further classification using an appropriate coding scheme.
	A qualitative-quantitative post-test.	
	- Part A (same as pre-test's)	- Data were elaborated following the same approach applied for pre-test's data analysis. For the experimental group's data, a coding scheme based on the research-informed materials was used. Correspondingly, for the comparison group's data, a coding scheme based on the current curriculum was used. However, the two coding schemes were developed in such way that their use to led to similar coding scheme used for the analysis of pre-test's part A data. - Furthermore, a comparative study of the experimental students' results to the comparison group corresponding results was carried out.
	- Part B.	- Data collected through the qualitative questions of post-test's part B were elaborated using a similar approach to that applied for part A data analysis. - Data collected through the quantitative questions of post-test's part B, were analyzed on a correct/incorrect basis and were classified in categories and sub-categories of responses. - Moreover, a comparative study of the experimental students' results to the comparison group corresponding results was carried out.
	Video recordings.	- Data collected from video recordings were analyzed with the use of a rubric consisted of three parts: the first part concerned the content of the lessons, the second the instructional means used and the third one, the kind of classroom talk applied.

RQ3. How do the understandings of the energy concept, of a small sub-group of students, develop during the lessons of the research-informed approach?	**A qualitative pre-test.** - Part A.	 -Students' responses to each question of part A were analyzed by applying a two-stage analysis approach. In the first stage, responses to each individual question were studied and the various different quotes were identified. These were used for the formulation of sets of coding categories which were describing the qualitative different ways in which the students responded to the tasks of each individual question. In the second stage, coding categories comprised in each set were studied and subjected to further classification using an appropriate coding scheme.
	A qualitative-quantitative post-test. - Part A (same as pre-test's)	 - Data were elaborated following the same approach applied for pre-test's data analysis. A coding scheme based on the research-informed materials was used.
	- Part B.	- Data collected through the qualitative questions of post-test's part B were elaborated using a similar approach to that applied for part A data analysis. - Data collected through the quantitative questions of post-test's part B, were analyzed on a correct/incorrect basis and were classified in categories and sub-categories of responses.
	Two short-length diagnostic probes. - First short-length diagnostic probe.	 - A similar approach to part A pre and post-test data analysis was followed.
	- Second short-length diagnostic probe.	- A similar approach to part A pre and post-test data analysis was followed.
	Individual interviews. Experimental students. -First interview.	 - Written records were developed

		from audio recorder memory. The students' responses on each question of the interview protocols were studied and from these, quotes revealing the students' understanding on the energy ideas being probed by each question were drawn. Each quote was analyzed with the use of a coding scheme and commented on the grounds of the extent of the students' understanding on the energy idea being probed.
	- Second interview.	- A similar approach to that used for the first interview's data analysis was followed. - Furthermore, the energy learning profile of each of four experimental students interviewed was developed through a case study. Each student's case was contextualized with data from the pre and post-test, the two short-length diagnostic probes and the two interviews.
	- Experimental teacher.	- Data collected from the experimental group teacher were exposed to a thematic analysis and commented on the g rounds of the researcher's observations.

CHAPTER 4 -THE DESIGN OF THE TEACHING SEQUENCE: METHODOLOGICAL BASIS AND PRACTICAL DECISIONS

In Chapter 2, the international science education literature concerning energy was reviewed. Previous research has followed two main directions: the investigation of students' alternative interpretations about energy and the development of instructional approaches for teaching energy. Discussion then turned to a detailed presentation of the design decisions made in every step of setting up the design study carried out in this doctoral thesis.

This chapter presents how insights gained about students' alternative interpretations were used to inform the designing and development of an innovative instructional approach to teach energy within a Cyprus high school context. Insights gained from critical review of the various proposals for teaching energy are used in the development of the theoretical framework for the innovative instructional approach. The chapter concludes with an account of the instructional intervention carried out.

4.0 INTRODUCTION

This chapter describes the *design decisions* that were taken to teach energy in a Cyprus upper secondary school context. It draws upon a perspective on making decisions in science teaching set out by Leach, Scott and associates (Ametller, Leach and Scott, 2007; Leach and Scott, 2003; Scott, Leach, Hind and Lewis, 2006). There are other perspectives that could have been used (see, for example: Ruthven, Laborde, Leach and Tiberghien, 2008). Leach and Scott's perspective was chosen because they were supervising this doctoral thesis, and their perspective informs design decisions at a fine grain size. Grain size (Leach and Scott, 2008) addresses the level of detail of design decisions; a decision about the precise method of introducing some detail about the teaching of energy is at a fine grain size. Furthermore, decisions at a fine grain size concern both the treatment of content and pedagogic strategies.

The perspective, advocates summarizing design decisions in a *design brief.* This sets out the curriculum context in which the science teaching is set (as this is a key influence on design decisions), and decisions about the content and pedagogy. The curriculum content identified for the design presented in this thesis is set out in sections 4.3 and 4.4. Three key pedagogical issues in the design are: Staging the scientific story, this relates to the way the scientific point of view is made available to students in the teaching process; supporting student internalization, this relates to the ways the teacher might act to help students make sense of, and apply the scientific point of view; handing-over responsibility to students, this relates to involving students into activities aiming to support internalization. Content-related design decisions are informed by the Learning Demand design tool. The learning demand tool as used in this design is set out in section 4.5. Pedagogic decisions are informed by many things, notably the craft knowledge of the science teacher. However, *some* design decisions about teacher/student talk were informed by the use of Communicative Approach design tool, which is set out in section 4.8. Throughout the chapter, examples from the teaching sequence itself are drawn upon to illustrate the design decisions. In Leach and Scott's terms (2006) this is a *working example* of one way that the design brief can be addressed.

4.1 CYPRUS EDUCATIONAL SYSTEM

The Cyprus Educational System consists of four levels: pre-primary, primary, secondary and higher educational.

Compulsory education starts for children who reach the age of 5 years with a one year program in Pre-Primary School. At the end of the program, leavers receive a Certificate of Attendance.

Pre-Primary School is followed by a six-year compulsory schooling in Primary School. The main evaluation procedure adopted is the continuous one. No written examination is given at any level. At the end of their six-year schooling, leavers receive the Leaving Certificate.

General Secondary Education offers six-year programs of education for children aged twelve to eighteen. It is divided into three-year cycles: Lower Secondary School (Gymnasium) followed by Upper Secondary School (Lyceum).

Lower Secondary School (Gymnasium) provides a three-year compulsory schooling and has a general orientation education in which a broad spectrum of subjects are offered. A public primary school leaving certificate is required for attending Gymnasium. Upon completion of education in Gymnasium a school Leaving Certificate is awarded.

Upper Secondary School (Lyceum) is open to all students who have successfully completed the Gymnasium. It offers a three-year education which follows a more flexible and diverse orientation with various specializations, depending on individual inclinations, skills and interests of the student. Attendance is compulsory for the successful completion of graduation requirements and leads to a school leaving certificate 'APOLYTIRION'.

In parallel to Lyceum, there is also the Technical Education with a Technical and a Vocational stream. The syllabus in the Technical stream emphasizes science subjects whereas in the vocational stream technological subjects, workshop practice and industrial training are emphasized. Upon completion, students are also awarded the 'APOLYTIRION'.

Higher Education is provided by both state and private institutions which operate at university and non-university level. State universities are the University of Cyprus, the Open University of Cyprus and the Cyprus University of Technology. They offer courses at undergraduate and post-graduate level (Masters and PhDs).

As far as it concerns physics instruction, this takes place in primary education within the context of science lessons whereas in secondary education it exists as an individual subject. In particular, in lower secondary education, physics is taught in the second and third grade for two lessons per week and participation in a final examination is required by the students. In upper secondary education, physics is taught in the first grade and the second grade of general education also for two lessons per week. For the first grade, participation in a final exam is required of the students. Furthermore, advanced physics is taught in the second and the third grade for six and four lessons per week respectively. Participation in a final examination is optional for the students.

The structure of the Cyprus Educational System is illustrated in Figure 4.1 (http://www.moec.gov.cy).

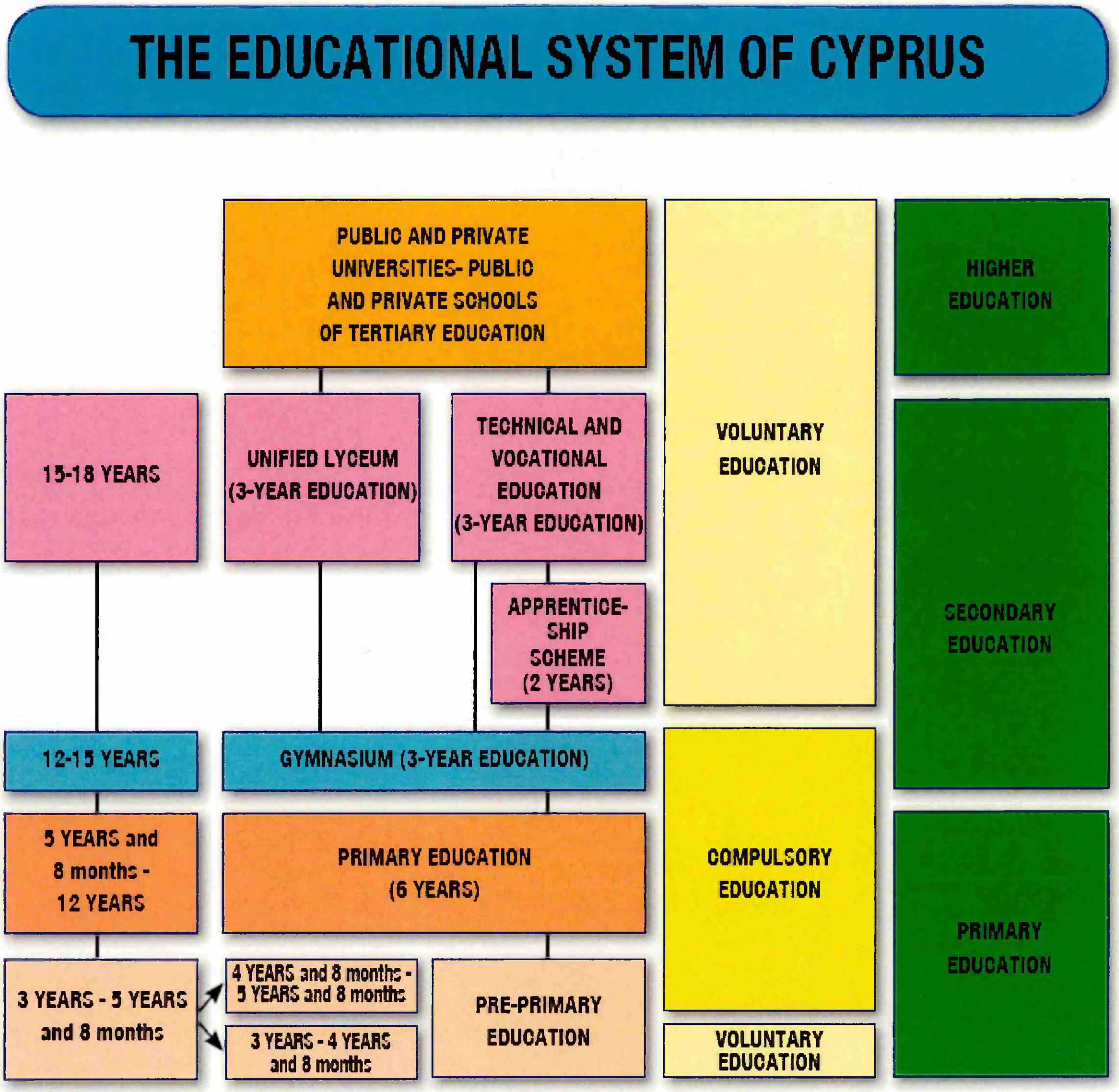


Figure 4.1: The Educational System of Cyprus

4.2 OVERVIEW OF THE DESIGN BRIEF OF THE PROPOSED INNOVATIVE INSTRUCTIONAL SEQUENCE FOR ENERGY

The design brief developed for the description and justification of the design intentions of the innovative instructional sequence for energy proposed in this doctoral thesis is illustrated in Table 4.1. The theoretical framework proposed by Leach, Ametller and Scott (2011) in setting up of a design brief is presented in detail in Appendix O.

Table 4.1: Design brief of the instructional sequence of energy
Context for the designed teaching • ***Curriculum*** -Energy in the Cyprus Educational System (section 4.4) -Discussion of energy in the Cyprus Educational Curriculum (section 4.5) • ***Students*** Information concerning the participated students is included in Chapter 3-Research Methodology • ***Teachers*** Information concerning the participated teachers is included in Chapter 3-Research Methodology • ***Institutional constrains*** Information concerning the institutional constrains is included in Chapter 3-Research Methodology
Detailed content aims of the teaching • Evidence informed design of science instructional interventions-Learning demands-Teaching goals (section 4.5) • Theoretical framework for energy: Four pre-requisites (section 4.6) • Proposed theoretical framework (section 4.7)
Specification of the pedagogic strategies and sequencing of content to be used in the teaching • Communicative approach (section 4.8) • Overview of the design and development procedure of the research-informed teaching sequence (section 4.9) • Development of the innovative instructional sequence (section 4.10).

4.3 ENERGY IN THE CYPRUS EDUCATIONAL SYSTEM

In the Cyprus Educational System, the formal instruction of energy begins in the sixth grade (students aged 11-12 years) of primary school. This takes place in the third trimester within the time of six 40-minute lessons with the focus being placed on the presentation of forms of energy, energy sources and the description of energy transformations from one form to another.

Energy appears again in the second grade of lower secondary school (students aged 13-14 years). As it is defined in the curriculum, its instruction takes place in the first trimester within the time of seven lessons first in the chapter of Matter and Energy and then as a brief part of Heat. The focus is placed on the presentation of forms of energy and sources of energy whereas energy transformations from one form to another and the conservation of energy principle are briefly presented.

The instruction of energy continues in the first grade of upper secondary school in an individual chapter and takes place in the third trimester within the time of eight lessons. The conceptual sequence followed leads to a more traditional approach for the instruction of energy with its origin in classical mechanics. The starting point of this sequence is the introduction of the concept of work, then it proceeds to the introduction of kinetic energy and potential energy (elastic and gravitational), to treatment of the transformations between these mechanical forms and finally, to the introduction of the energy conservation principle of mechanics. Furthermore, much emphasis is placed on the quantitative application of the conservation principle of mechanics in the analysis of energy problems. The content of the curriculum for the first grade of upper secondary school concerning energy is illustrated in Table 4.2.

Table 4. 2: Cyprus National Curriculum for Physics for the first grade of upper secondary school.

CONTENT	TEACHING GOALS	LESSONS
CHAPTER 6 Work, Power and Energy	The students should:	8
6.1. Work done by a	6.1.1 Recognize that when a force is exerted on an object	1

constant force.	initially at rest and causes its movement, there is an amount of energy transfer to the object, called work done by the force. 6.1.2 Interpret the positive, negative or zero value of the work done by a force (in each case). 6.1.3 Calculate the work done by the constant force.	
6.2. Work done by a variable force whose direction is constant.	6.2.1 Calculate the work done by a variable force whose direction is constant.	1
6.3. Kinetic energy and work-energy theorem.	6.3.1 Express the change in kinetic energy of an object as the work done by a resultant force which is exerted on it.	1
6.4. Power	6.4.1 Recognize how useful can be the calculation of the rate with which energy is transferred or transformed into another form (and to give examples). 6.4.2 Define power as the rate with which an amount of energy is transferred or transformed from one form into another. 6.4.3 Define the power unit in S.I.	1
6.5. Gravitational potential energy.	6.5.1 Recognize that within the gravitational field, work is done by the gravitational force (weight) which is exerted on the objects. 6.5.2 Define gravitational potential energy as the amount of energy stored in the system object-earth and relate gravitational potential energy to the work done by the weight. 6.5.3 Calculate the work done by the weight in the case where the magnitude of weight is approximately constant.	1
6.6. Elastic potential energy.	6.6.1 Verify experimentally Hooke's law. 6.6.2 Define elastic potential energy.	1 1
6.7. Mechanical energy and conservation of mechanical energy.	6.7.1 Define mechanical energy as the sum of the kinetic and the gravitational potential energy and explain the meaning of this sum.	1

Energy is also included in the advanced physics curriculum in the second grade (students aged 16-17 years) of upper secondary school where it is dealt with in a separate section in the context of mechanics. The instruction takes place in the first trimester within the time of six lessons. Regarding the content, this is a review of what is taught in the first grade with the emphasis being placed on more advanced quantitative applications in the analysis of energy problems in relation to motion.

A detailed account of the energy curriculum within the Cyprus Educational System is presented in Appendix P.

4.4 DISCUSSION OF ENERGY IN THE CYPRUS NATIONAL CURRICULUM

In the previous section the current Cyprus National Curriculum concerning energy was presented in detail. The study of the current curriculum from a critical point of view leads to the conclusion that both the content and the approach are not effective in promoting conceptual understanding of the concept of energy. As far as it concerns the primary and the lower secondary classes, the content is restricted to the presentation of forms and sources of energy and the description of transformations from one form to another. Regarding the upper secondary classes and in particular, the first grade, the traditional approach according to which the instruction of energy starts with the introduction of mechanical work, proceeds to the mechanical forms of energy and ends with the introduction of the conservation of mechanical energy theorem is followed. Due to the fact that quantitative treatment is available, emphasis is placed on the numerical applications of the principle in the analysis of energy problems. Furthermore, the instruction of the energy concept is not based on the grounds of an integrated theoretical framework within which understanding of the basic aspects of the concept of energy is promoted. Here, the transformation of energy aspect dominates and the aspect of conservation is introduced through the conservation of mechanical energy theorem which however, is a conditional expression of the conservation of energy principle. Furthermore, the aspect of degradation is discussed through a limited number of worked examples. Thus, the instruction of the aspects of energy store, transfer, conservation and degradation although included in the energy knowledge to be taught, are not explicitly introduced.

Having all the above in mind, there is a need to design an innovative teaching sequence through which conceptual understanding of the concept of energy can be promoted. A key issue is whether the current Cyprus National Curriculum for Physics concerning energy should be taken into consideration in the development of the innovative teaching sequence or the latter should be developed independently. After some consideration, it was decided that the curriculum should be taken into account. This was in order that possible claims about learning outcomes be valid from a research methodology perspective, including in relation to ethics and for practical reasons. As is presented and discussed in the previous chapter of research methodology, the study carried out in this doctoral thesis aimed at the evaluation of the effectiveness of an innovative instructional approach for energy in comparison to the existing approach. In order for the comparison of the two approaches to teaching energy to be valid, the same energy content should be addressed to the experimental and comparison groups respectively. In that way, the two groups would be treated fairly in terms of knowledge on energy. Turning to the ethical and practical reasons, the main argument was that the students who would be taught through the innovative teaching sequence would be examined on the same final examination test with students taught through 'normal' teaching. Furthermore, in examining the content of the current curriculum it was decided that the integration of the ideas on energy included in it would not cause serious difficulties in the development of the innovative teaching sequence. One such an example concerned the inclusion of the conservation of mechanical energy theorem; as it is already discussed, the theorem consists conditional expression of the general principle of the conservation of energy and thus, its inclusion in the innovative instructional sequence would rather provide an additional learning opportunity.

Since it was decided that the content of the current curriculum concerning energy would be taken into account, the international science education literature (Chapter 2) was searched extensively looking for reports on designing schemes which could be used for the reconstruction of it into the innovative teaching sequence. Critical review of those reports resulted in focusing much interest on research evidence-informed designing of science instruction interventions (Scott, Leach, Hind and Lewis, 2006). Moreover, it was decided that the innovative teaching sequence would take the form of a research-informed one.

4.5 EVIDENCE-INFORMED DESIGN OF SCIENCE INSTRUCTIONAL INTERVENTIONS

The international science education literature provides evidence that not only energy but also many other scientific topics have been the focus of extensive research. Research activity mainly aimed to reveal students' alternative interpretations about energy on one hand and on the other hand the development and evaluation of innovative instructional sequences to teaching a specific scientific topic. Leach and Scott (2002) remark that although there are many studies focusing on how instructional sequences might be designed and evaluated, only a few deal explicitly with how insights gained on students' 'everyday' views [1] might be used in combination to school science to the design and evaluation of instructional sequences.

In a later work, Scott et al. (2006) propose that science instructional sequences might be designed drawing upon two distinctively different groups of insights: those revealed from empirical studies, namely the students' 'everyday' views, referred to as 'evidence' (Scott et al., 2006, p.61), and; those '... developed through research and scholarship in science education and other fields, and are typically referred to as 'theory' ...' (Scott et al., 2006, p.61). Insights referred to as 'theory' are theoretical, informing about '... the nature of knowledge, thinking, learning and teaching' (Scott et al., 2006, p.61). As they clarify, insights referred to as 'theory' influence the way insights from empirical studies are interpreted so as to be used as 'evidence' about a particular scientific topic. Thus, a design of a science instructional sequence which takes into consideration the students' 'everyday' views about a specific topic and the school science is referred to as 'a research evidence-informed design of science teaching interventions'.

Furthermore, Leach and Scott (2002, p. 125) introduced the concept of 'learning demand' as a tool for designing and evaluating research evidence-informed interventions. The concept of 'learning demand' originates from Bakhtin's notion of 'social languages' (Bakhtin, 1986 as cited in Leach and Scott, 2002, p. 125). According to the researchers, students use a social language when discussing phenomena and events in everyday life, which include many of their alternative interpretations; this constitutes the everyday social

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[1] In Leach and Scott perspective, the terms 'students' 'everyday' views' and 'students' 'everyday' reasoning' are used to describe the students' views about a science topic prior to formal teaching.

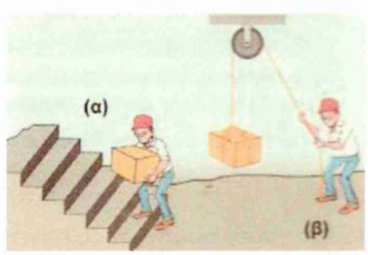
In this doctoral thesis, the term used corresponding to the above ones is 'students' alternative interpretations' about energy. The use of this term was based on the belief that students at the age group of 15-16 year under study, clearly do not use only 'everyday' understanding about energy when confronted with a phenomenon or an event; rather, they use their 'everyday' understanding together with knowledge on energy built up form past teaching of the concept. Furthermore, within the current scientific beliefs energy is considered as having an interpretive (and at up to an extent a predictive) power but not an explanatory one.

language of students. On the other hand, formal science instruction involves learning of a different social language, the social language of science. Drawing upon these, the concept is defined as follows: 'The concept of 'learning demand' offers a way of appraising the *differences* between the social language of school science and the everyday social language which learners bring to the classroom. The purpose of identifying learning demands is to bring into focus the intellectual challenges facing learners as they address a particular aspect of school science; teaching can then designed to focus on those learning demands' (Leach and Scott, 2002, p. 126).

Expanding on how learning demands for a particular scientific topic could be specified, the researchers identify three ways in which differences between the everyday and the school science social languages might arise. As they state: 'These relate to differences in the *conceptual tools* used, differences in the *epistemological underpinning* of those conceptual tools, and differences in the *ontology* on which those conceptual tools are based' (Leach and Scott, 2002, p. 126).

Focusing on the instruction of the concept of energy within a Cyprus high school context with which this doctoral thesis deals, various learning demands are identified. These arise from differences between the patterns of reasoning, the ontology and the epistemology of the interpretations of events occurring in a physical system formulated in everyday social language by the students and in the school science social language. Many of these learning demands are presented and discussed in detail in section 4.10.3.

An example of a learning demand which arises from a difference between the students' pattern of reasoning and the school science view concerns the amount of energy in the gravitational store of the system object-Earth when an object is lifted to a height through different pathways. One such a case is illustrated in the figure below.



When high school students are asked to compare the amount of energy in the gravitational store in the system box-Earth, if the box is lifted at same height through the stairs and using a pulley, they state that it is greater when the box is lifted through the stairs (section 2.7). They justify their response stating that when the box is lifted through the stairs, the pathway is longer than that when lifted using the pulley. By contrast, school science view states that the amount of energy in the gravitational store of the system object-Earth, when an object is lifted up between two vertical positions, is proportional to the distance between the two vertical positions and does not depend on the pathway followed by the object when it moves between the two vertical positions. Thus, the amount of energy in the gravitational store of the system box-Earth is the same for both pathways.

A learning demand of great importance for conceptual understanding of energy results from differences in the ontological consideration of the concept in school science and in everyday contexts. In science, energy is regarded as an abstract mathematical idea; rather, in the everyday context energy is regarded as substantial in nature.

Another learning demand of also great importance in coming to understand energy, results from differences in the epistemological consideration of the concept in school science and in everyday contexts. According to scientific view, energy is a unifying idea which was invented to facilitate the interpretation of various different changes occurring in a range of physical systems. However, students often do not appreciate the unifying character of energy and tend to use other concepts such as 'force', 'movement' and 'speed' in their interpretations of phenomena and events.

After having identified the learning demands of a specific topic of science, Scott et al., (2006) propose that considerations on how these demands might be addressed through instruction should be made. They introduce the concept of 'teaching goals' (Scott et al., 2006, p.65) for a much more detailed-a 'fine grained' (Leach and Scott, 2008) analysis of the learning points on which the teacher should focus on during instruction. Furthermore, these are described as follows: 'The teaching goals make explicit the ways in which the students' ideas and understandings are to be worked on through the intervention and guidance of the teacher. Once the teaching goals have been clarified, attention can be given to considering what teaching activities might be used to address these goals' (Scott et al., 2006, p.68). The researchers emphasizing the importance of specifying the teaching goals when designing science instructional interventions state that: 'It seems to us that one of the clear strengths of the research evidence-informed approach to planning outlined here is the detailed analysis leading to the identification of teaching goals. Through this kind of analysis the 'conceptual terrain' of the teaching and learning domain is laid out and the teacher becomes more aware of what is involved for the students in learning in this area and what the teacher might do to support that learning' (Scott et al., 2006, p.76).

Turning to the instruction of energy within a Cyprus high school context, a set of teaching goals are identified in order that the concept can be effectively addressed by the teacher. The teaching goals identified for each particular learning demand are presented and discussed in detail in section 4.10.4. Furthermore, the activities created to address each teaching goal are described also in detail in each of the ten lessons of the innovative instructional sequence in section 4.10.4.

Overall, according to research evidence-informed approach, the design and development of a research-informed science teaching intervention includes a four-step scheme as follows (Leach and Scott, 2002, p. 127, Scott et al., 2006, p. 66):

1. Identify the *school science* knowledge to be taught.
2. Consider how this area of science is conceptualized in the *everyday* reasoning of students.
3. Identify the *learning demands* by appraising the nature of any differences (conceptual, epistemological, ontological) between 1 and 2.
4. Designing a *teaching intervention* to address each aspect of this learning demand:
   a. identifying the *teaching goals* for each phase of the intervention
   b. planning a sequence of *activities* to address the specific teaching goals
   c. specifying how these teaching activities might be linked to appropriate *forms of classroom communication.*

4.6 A THEORETICAL FRAMEWORK FOR ENERGY: FOUR PRE-REQUISITES

Working in the direction of the designing and development of the research-informed teaching sequence for energy it was decided that this would enable students to acquire an insight concerning the role of energy in science, as a way of thinking for describing the observed changes in a physical system, as a physical process takes place in it. In addition, the theoretical framework should satisfy four main prerequisites: firstly, it should be consistent, that is, the way of presenting the concept of energy be valid within the current scientific beliefs. Secondly, it should be coherent, meaning that the ideas be presented and expressed in an explicit way, not allowing thus, the creation of alternative conceptions of any kind. Thirdly, it should be generalizable, that is, the same ideas presented and expressed could be applied in a variety of different situations. Fourthly, it should enable the full quantitative description of the concept, since this is available in the age level of 15-16 years old.

Among all insights gained by critical reviewing of perspectives on teaching and learning of energy (Chapter 2), much interest was focused on the ideas proposed within the SPT11-14 (2006, Lawrence, 2007) project (section 2.13) since these were considered to fulfill the four prerequisites been set and thus, they could be used as a basis upon which the innovative teaching sequence could be developed. More explicitly, concerning the first prerequisite it was proposed that energy is abstract in nature, calculable and conserved quantity, which is consistent to the current scientific view of energy. Regarding the second prerequisite, this is also fulfilled since the energy ideas are both expressed explicitly by a limited list of energy stores and pathways and moreover, are explicitly presented by the visual representations. Furthermore, the third prerequisite is fulfilled since the ideas of the various kinds of energy stores which can emptied and filled along various kinds of pathways with the amount of energy being conserved can very well applied in a variety of processes and physical systems. Finally, the fourth prerequisite is also fulfilled because, as it is suggested in the following, a mathematical description could be added to the proposed physical and energy descriptions.

The ideas proposed within the SPT11-14 project were studied carefully and intensively. After a series of various developments and taking into account the content of the current

Cyprus curriculum, the theoretical framework of the research-informed teaching sequence was developed. The developments made and the final version of the theoretical framework are presented and discussed in detail in a following part.

4.7 PROPOSED THEORETICAL FRAMEWORK

In this part, the theoretical framework proposed in this doctoral thesis is presented and discussed in detail. Furthermore, a worked example is discussed.

According to the proposed theoretical framework:

- Energy is a unifying concept, abstract and mathematical in nature.

- Energy is a property of systems which is related to four key aspects:

  - *Aspect 1:* Energy can be stored. The places at which an amount of energy can be found are defined as ***energy stores***. The amount of energy in an energy store can be calculated in different ways to different stores.

Some energy stores are defined as follows:

Gravitational store: when an object is at a raised position above the centre of a planet or some other reference point, there is energy in a gravitational store of the system object-planet.

The amount of energy of a gravitational store changes when the raised position of the object above the centre of the planet or other reference point increases or decreases.

Kinetic store: a moving object has energy in a kinetic store.

The amount of energy of a kinetic store changes when the magnitude of the velocity of the object increases or decreases.

Elastic store: a deformed (stretched or compressed) elastic object has energy in an elastic store.

The amount of energy in an elastic store changes when the deformation (stretching or compression) of the elastic object increases or decreases.

Chemical store: when a chemical reaction between two substances occurs (for example fuel and oxygen), there is energy in a chemical store of the system reactant-reactant, due to the kinds of bonds between the atoms or molecules which consist the reactants.

The amount of energy of a chemical store changes when reactants are combined or separated to give products.

Internal store: a solid, a liquid or a gas has energy in an internal store. Internal store is consisted of two parts: the energy because of the continuous motion (kinetic store) of the particles (atoms, molecules) from which an object or a substance is made up and, the energy of the chemical bonds between the atoms or the molecules.

The amount of energy of an internal store changes when the temperature of the object or the substance increases or decreases because the energy of the kinetic store of the particles increases or decreases respectively.

The amount of energy in the energy stores can be represented with a simple bar notation. Changes in the amount of energy in an energy store can be represented with an increase or a decrease of the height of the bar. In this intervention, the following representations of each of the energy stores were designed. Furthermore, the amount of energy in the energy stores defined earlier in various cases can be represented as illustrated in Figure 4.2.

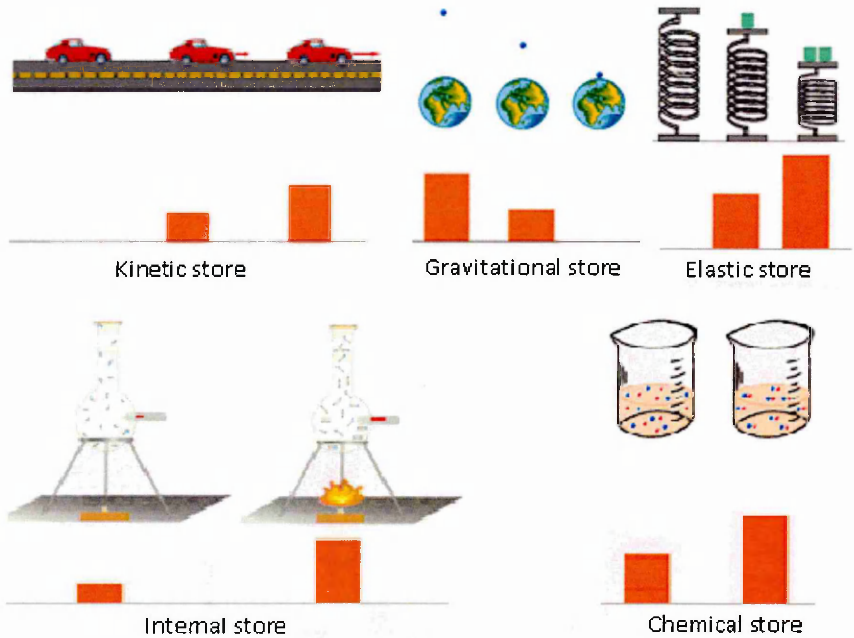


Figure 4.2: Representations of selected energy stores.

Concerning the idea of energy stores as introduced within the SPT11-14 project, this was subjected to developments aimed to facilitate its more effective teaching and learning. These are discussed below.

Earlier in this part, it was proposed that energy stores be represented with a simple bar notation wherein the increase or decrease in the amount of energy in an energy store corresponds to an increase or decrease of the height of the bar. This development was considered important for the following reasons: first, the visual representations of energy stores as tanks in which the level of the content amount of energy increases or decreases when filling or emptying entails, as it is believed, the risk of considering energy as a fluid substance by the students. Moreover, it is believed that the use of the bar notation represents the nature of energy as a calculable abstract quantity in a more coherent way. Second, the use of a uniform bar notation for all kinds of energy stores can represent energy's unifying character with a more effective way. Third, which perhaps is the less important in relation to conceptual understanding of energy, the use of the simple bar notation can be proved a manipulable way of representing energy stores and the changes in the amount of energy by the students. This, as it is illustrated in the following through discussion on the worked examples, is particularly true in the cases of more complicated energy descriptions.

Lawrence defines energy stores as: '... places where one can pin down quantities of energy by calculation'. Furthermore, in another part of this paper (2007) he claims that:

> 'It is not, I think, helpful to locate energy in objects, as a significant number of cases the energy is calculated by considering the interaction between objects (e.g. two separated masses, two reactants combined to form a product). A solution is to insist on a quite separate level of description that exploits these natural tendencies, so giving a simple and accessible depiction, that can, I think, prove fruitful'.

Instead, the formulation of definitions for each energy store being introduced is preferred. In the cases where energy is calculated by considering interaction between objects (gravitational and chemical store), this can be overcome by referring to the interacting objects with the term 'system of objects'. Thus, gravitational store can be defined as the amount of energy of the ***system object-planet*** and chemical store as the amount of energy of ***system reactant-reactant***. The decision for this development was based on the researcher's experience as physics teacher knowing that when teaching about energy stores, a question which many students will pose is 'where' the quantity of energy is stored. Having this in mind, it was decided that the answer of such a question be included in the definitions of energy stores. Moreover, the use of definitions of energy stores in combination to depictions, that is, the use of verbal and visual representations is preferred, since it is considered that the visual representations of energy stores alone do not provide a coherent way of introducing energy stores. An example which it is believed that reinforces this decision is the visual representation of gravitational store; it is considered that it is not clear for a student whether the amount of stored energy is of the system object-planet or of the object.

A third and last development made concerned the use of the term 'internal store' instead of the term of 'thermal store' in order the risk of confusion due to language be voided. In Greek, the term 'thermal energy' is used as a synonym of the term 'heat'.

- *Aspect 2:* Energy can be transferred along ***transfer pathways*** from one energy store to another. Transfer pathways describe the process or the mechanism involved during the transfer of energy.

Some transfer pathways are defined as follows:

Mechanical working: when a force is exerted and its point of application is displaced in the direction of movement, then energy is transferred along a mechanical working pathway.

Heating: when two objects or substances of different temperature are in contact, then energy is transferred along a heating pathway. Energy is transferred either by the process of conduction in solids, by the process of convection in liquids and gases or by radiation, a process which can take place both in the presence and in the absence of matter.

Sound: when a cause (for example, the clap of hands, the knock on a door) sets the particles (atoms, molecules) within an object or a substance into vibration, then energy is transferred along a sound pathway.

Transfer pathways can be represented with the simple notation of an arrow. The direction of the arrow defines the direction of the energy transfer whereas the thickness of the arrow visualizes the amount of energy being transferred from one energy store to another.

Regarding the idea of energy pathways as this is proposed within the SPT11-14 project, the following developments were made.

First, the transfer of energy from one store to another can be represented with the simple notation of an arrow along all pathways instead of the different depictions proposed. This development is essential since it was considered that the depictions do not promote understanding of the mechanism or process involved in the transfer of energy along the specific pathway visualized, rather they entail the risk of confusion to students. Furthermore, these specific depictions are not considered as manipulable ways of representing the energy transfer along the various pathways by the students.

Second, as in the case of energy stores, definitions were formulated for the introduction of each pathway instead of the depictions proposed. This development is important since the depictions alone do not provide a coherent way of representing the process or mechanism involved in the transfer of energy along each pathway. Moreover, definitions are introduced in combination with the arrow notation, that is, by using both verbal and visual representations; as it is believed, these together can provide a full description of each pathway and facilitate thus a more effective understanding of the process or mechanism involved, the direction of the energy transfer and also, the amount of energy being transferred.

Third, the term 'pathways' was replaced by the term 'transfer pathways' since it was considered as more suitable in Greek language to express the transfer of energy from one store to another.

Fourth, the term 'transfer' instead of the term 'shift' of energy is proposed in order to avoid the risk of producing the misconception that energy is a substance in nature. In Greek, the term 'transfer' is usually used to express the 'movement' of an amount of energy along the heating, sound or light pathways or the movement of waves whereas, the term 'shift' is used to express the movement of an object from one position to another.

Fifth and last, the term 'heating' was replaced by the term 'heating by particles' since it was considered that entails the risk of confusion to students. This is due to the fact that the processes of conduction and convection involved along the heating pathway require the presence of matter whereas radiation does not necessarily requires the presence of matter, that is, no particles are present.

- *Aspect 3:* Energy is conserved. As the amount of energy of a store is decreased, the amount of energy of some other stores is increased and thus, the quantity of energy remains unchangeable.

- *Aspect 4:* Energy is degraded. Energy can be stored in stores which cannot be further useful.

Furthermore, changes which are observed in a system, as a physical process takes place in it, can be described in terms of energy changes, that is, as the emptying of an energy store with the simultaneous filling of other stores, with energy being transferred along specific pathways. As energy is transferred from one store to others, its amount remains the same.

In order the observed changes be described, the physical system in which they take place should be determined. Within this theoretical framework, the group of the objects involved in the occurrence of the changes is called ***a system***. Moreover, it is considered as useful a facet for the start and a facet for the end of the process be selected.

The transfer of energy within a system can be represented diagrammatically both qualitatively and quantitatively with a ***Sankey diagram*** (section 2.13). In a Sankey diagram, the different kinds of energy stores are represented with a simple rectangle bar whereas the changes in energy stores are represented with the increase or the decrease of the height of the bar. Also, the different kinds of transfer pathways are represented by an arrow. The direction of the arrow defines the direction of the energy transfer whilst its thickness shows the amount of energy being transferred from one energy store to another. An example of a Sankey diagram, in the case in which the energy is transferred from the initial to the final stores along three different transfer pathways is illustrated in Figure 4.3.

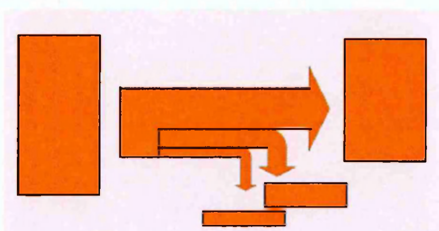


Figure 4.3: An example of a Sankey diagram

In the case of more complex systems where there is more than one energy transfer from the initial to the final store or stores, it is proposed that the course of energy be represented with ***a Full Sequence Energy Diagram***. Furthermore, it is proposed that in a Full Sequence Energy Diagram, each energy transfer from one energy store to another is represented as a single sub event. Thus, the course of energy from the initial to the final energy store or stores is represented as a sequence of different sub events. The general form of a Full Sequence Energy Diagram is illustrated in Figure 4.4.

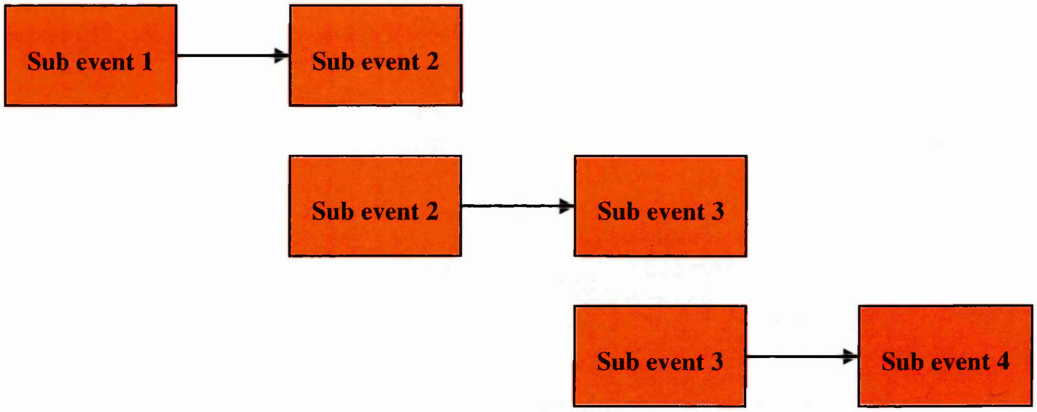
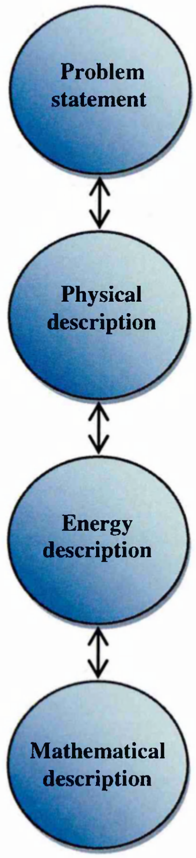


Figure 4.4: Full Sequence Energy Diagram

The diagrammatical representation of the transfer of energy within a system provides an effective teaching and learning tool since it promotes understanding of each of four aspects of the concept of energy through a simple and understandable visual way. As it is argued, this is particularly true in the case of the Full Sequence Energy Diagram which allows for a detailed study and interpretation of all changes which take place in a complex system in terms of energy through the sub-events. In particular, understanding of the store aspect is promoted through visualizing the energy of a system in an initial store corresponding to the first sub-event; understanding of the transfer aspect is promoted through visualizing the transfer of the energy of the system along the transfer pathways to the various energy stores corresponding to the subsequent sub-events; understanding of the conservation aspect is promoted through visualizing the amount of energy of the various energy stores corresponding to each subsequent sub-event with bars of such height which equals the height of the bar of the initial energy store, and; understanding of the degradation aspect is promoted through visualizing an amount or all the amount of the energy of a system being stored in internal stores which correspond to subsequent or the final sub-event. Furthermore, the visual representation of the transfer of energy within a system with the use of a Full Sequence Energy Diagram allows for quantitative treatment of each amount of energy being transferred along any of the transfer pathways or being stored not only in the final store but to energy stores corresponding to any subsequent sub-event.

In analyzing the physical changes which are observed in a system due to the evolution of a process, it is proposed that a sequence of four different kinds of descriptions can be used for their description. The four descriptions proposed are: the ‘problem statement’, the 'physical description', the 'energy description' and, the 'mathematical description'. These are defined as follows.



A description which serves as a source of information for both understanding the process which takes place in a system and for providing quantitative data.

A verbal description of the changes observed in a system in the natural world, as a physical process takes place in it.

A verbal and diagrammatical description of the changes observed in a system as a physical process takes place in it, expressed in terms of energy.

A quantitative description of both the changes in the amount of energy stores and the amount of energy being transferred along the transfer pathways, as a physical process takes place in a system.

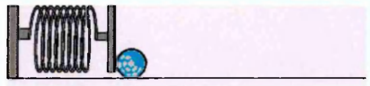
Within the SPT 11-14 project, only the physical and the energy descriptions are proposed for the analysis of the physical changes observed in a system. Proceeding beyond this point, it is proposed that a problem statement description may precede the physical and the energy descriptions and a mathematical description may follow them. The development of including a problem statement description first in the sequence of descriptions was based on the believe that a depiction alone, usually an image, may not provide all the required information for a qualitative and quantitative treatment of the physical changes observed in the system under study. Furthermore, a mathematical description is included since the quantitative treatment is available in the first grade of upper secondary school level and may be the last in the sequence of descriptions since the other three may be supportive or even necessary in order to take place.

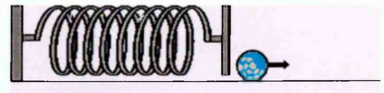
An example in which the sequence of the descriptions is applied for the analysis of the changes between two snapshots of a process is the following:

Problem statement

A spring of elasticity constant 50 N/m is 10 cm long when it is compressed and 20 cm long when it is stretched. The small metallic ball is of mass 0.1Kg and it is free to roll on a horizontal plane.
Calculate:

a. The amount of energy of the system at the beginning of the event.
b. The speed of the ball right after it is set into motion.





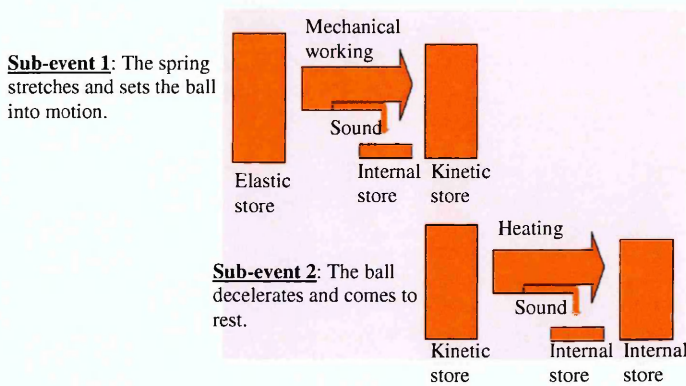
Physical description

The spring stretches and sets the ball into a decelerated motion which finally comes to rest.

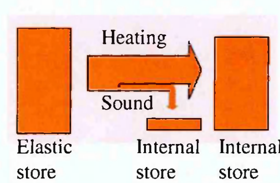
Energy description

Verbal energy description
The energy of the system is initially in the elastic store of the compressed spring. Hence, it is transferred along a mechanical working pathway to the kinetic store of the ball and along a sound pathway to the internal store of the surrounding air. Then, the energy in the kinetic tore of the ball is transferred along a heating pathway to the internal store of the horizontal plane, the ball and the surrounding air and along a sound pathway to the internal store of the surrounding air.

Diagrammatical energy description
Full Sequence Energy Diagram



Sankey Diagram



Mathematical description

Energy in the Elastic store=$1/2k\Delta l^2$
$=1/2.50.(0.20\text{-}0.10)^2$
=0.0025 J

Kinetic store=Elastic store=0.0025J
Kinetic store=$1/2.m.u^2 \Rightarrow$
$0.025=1/2.0.1.u^2 \Rightarrow$
u=0.22 m/s

4.8 COMMUNICATIVE APPROACH

As proposed by Scott et al. (2006) and referred to earlier, in order for each teaching goal to be addressed, a sequence of activities should be planned which should also be linked to appropriate 'forms of classroom communication'. Mortimer and Scott (2003) introduced the concept of 'communicative approach' to be used as a design tool for the specification of the different kinds of talk which might be involved in each activity between teacher and students.

The concept of communicative approach was developed along two dimensions: 'authoritative/dialogic' and 'interactive/non-interactive' (Mortimer and Scott, 2003, p.33). Taking the authoritative/dialogic dimension, authoritative discourse is defined as that in which the teacher controls the direction of the classroom talk on just one point of view, that is, the teacher focuses students' attention on the school science point of view. Authoritative discourse does not allow the bringing together or the exploration of ideas expressed by the students. In cases in which students express ideas or raise questions which do not contribute to the development of the pursued school science point of view, they are not taken into account by the teacher. Alternatively, if an idea expressed by a student is considered as helpful by the teacher in the development of the pursued school science point of view, it is used by the teacher.

On the other hand, dialogic discourse is defined as that in which the teacher allows for different points of view, everyday and scientific, to be expressed and taken into account. Thus, dialogic discourse might involve the teacher elucidating the students' everyday views on a specific scientific topic at the start of an instructional sequence, or; comparing and contrasting students' initial ideas on a specific scientific topic to the scientific point of view at a later stage of an instructional sequence, or; encouraging discussions between students on how an introduced scientific idea might be applied for the formulation of an explanation on a novel problem, also at a later stage of an instructional sequence.

Furthermore, the key characteristics of both the authoritative and the dialogic discourse were summarized by Scott, Mortimer and Aguiar (2006, p.610) in Table 4.3.

	Authoritative Discourse	Dialogic Discourse
Basic definition	• focusing on a single perspective, normally the school science view.	• open to different points of view
Typical features	• direction prescribed in advance	• direction changes as ideas are introduced and explored
	• clear content boundaries	• no content boundaries
	• no interanimation of ideas	• variable (low-high) interanimation of ideas
	• more than one point of view may be represented but only one is focused on	• more than one point of view is represented and considered
Teacher's role	• authority of teacher is clear	• teacher assumes a neutral position, avoiding evaluative comments
	• teacher prescribes direction of discourse	
	• teacher acts as a gatekeeper to points of view	• greater symmetry in teacher–student interactions
Teacher's interventions	• ignores/rejects student ideas	• prompts student contributions
	• reshapes student ideas	• seeks clarification and further elaboration
	• asks instructional questions	• asks genuine questions
	• checks and corrects	• probes student understandings
	• constrains direction of discourse, to avoid dispersion	• compares and contrasts different perspectives
		• encourages initiation of ideas by students
Demands on students	• to follow directions and cues from the teacher	• to present personal points of view
	• to perform the school science language following the teacher's lead	• to listen to others (students and teacher)
	• to accept the school science point of view	• to make sense of others' ideas
		• to build on and apply new ideas through talking with others

Table 4.3: Key features of authoritative and dialogic discourse.

Turning to the second dimension 'interactive/non-interactive, interactive talk is defined as that in which more than one person participates. On the other hand, non-interactive talk is defined as that in which just one person participates, usually the teacher.

Combining the two dimensions, Mortimer and Scott (2003) identify four fundamental classes of communicative approach as follows: 'interactive/dialogic', 'non-interactive/dialogic', 'interactive/authoritative' and, 'non-interactive/ authoritative'. The four classes of communicative approach are explicitly described in Figure 4.5 (Scott et al., 2006, p. 73).

	INTERACTIVE	NON-INTERACTIVE
DIALOGIC	**A: Interactive/ Dialogic:** the teacher seeks to elicit and explore students' ideas about a particular issue with a series of 'genuine' questions.	**B: Non-interactive/ Dialogic:** the teacher is in presentational mode (*non-interactive*), but explicitly considers and draws attention to different points of view (*dialogic*), possibly in providing a summary of an earlier discussion.
AUTHORITATIVE	**C: Interactive/ Authoritative:** the teacher typically leads students through a sequence of instructional questions and answers with the aim of reaching one specific point of view.	**D: Non-interactive/ Authoritative:** the teacher presents a specific point of view.

Figure 4.5: Four classes of communicative approach.

Mortimer and Scott (2003) relate communicative approach to teaching purposes. In a later paper, Scott et al. (2006, p. 613) state that: 'It is clear that as a sequence of teaching progresses, different purposes are addressed by the teacher with each purpose relating to a particular phase of a lesson within an overall lesson sequence. The teaching sequence which we have identified (Mortimer & Scott, 2003) are as follows:

1. Opening up the problem;
2. Exploring and probing students' views;
3. Introducing and developing the scientific story;
4. Guiding students to work with scientific ideas and supporting internalization;
5. Guiding students to apply, and expand on the use of, the scientific view and handing-over responsibility for its use;
6. Maintaining the development of the scientific story'.

Emphasizing the strengths of communicative approach in science instructional sequences Scott et al. (2006, p. 606) state that: '... any sequence of science lessons, which has as its learning goal the meaningful understanding of scientific conceptual understanding of scientific conceptual knowledge, must entail *both* authoritative and dialogic passages of interaction. Indeed, from the perspective that we take, we see a *tension* between authoritative and dialogic approaches as being an inevitable characteristic of meaning making interactions in science classrooms'.

In the following, the use of each of four classes of communicative approach in the designing of the lessons consisting of the innovative instructional sequence of energy is illustrated and discussed. For this purpose, Activity 2.2 of the Lesson 2 plan concerning the introduction of the conservation of energy principle is presented as a worked example. Prior to the presentation and discussion of Activity 2.2, the school science to be taught and the students' 'everyday' views concerning the aspect of the conservation of energy are identified. This is followed by the identification of the learning demand concerning the aspect of the conservation of energy arising from the differences between the school science to be taught and the students' 'everyday' views. Finally, the corresponding teaching goal addressing the learning demand is identified.

Thus, the school science knowledge to be taught identified is: *The total amount of energy of a system remains constant. The idea of conservation is one of the key aspects of the concept of energy.* This is included in section 4.10.1 in which the energy context of school science to be taught in the proposed innovative instructional sequence is presented in detail.

Then, the students' 'everyday' views identified are: *Energy 'disappears' or 'stops to exist* (Orfanidou, 2007) *or 'is consumed'* (Ault et al., 1988) *at the end of a physical process.* These are included in section 4.10.2 in which the students' 'everyday' views concerning the energy ideas included to be taught in the innovative instructional sequence are presented.

Furthermore, the learning demand which arises is that: *Energy is a conserved quantity and thus, it does not 'disappear'/'stop to exist'/'consumed' at the end of a physical process.* This is presented in section 4.10.3 in which all learning demands resulted by appraising the differences between the energy knowledge to be taught and the corresponding 'everyday' views are presented in detail.

Finally, the teaching goal which addresses the learning demand is: *To enable students to built on the idea that the energy of a system is conserved.* This is included in section 4.10.4 in which the teaching goals identified for all learning demands presented in section 4.10.3.

At this point, the classes of communicative approach used in Activity 2.2 are presented and discussed.

....

Activity 2.2

Simulation *Sim 3* is presented on a screen to the class.

Approximate time

15 minutes

Mode of interaction

The teacher presents Page 1 of simulation *Sim3* and asks the students to study it carefully.

Page 1 of simulation *Sim 3* presents a smooth semi-spherical vessel in which a small ball rolls from its upper point to the bottom and then to the other upper point without friction. The ball's movement in the vessel is illustrated in the snapshots of Figure 4.6.

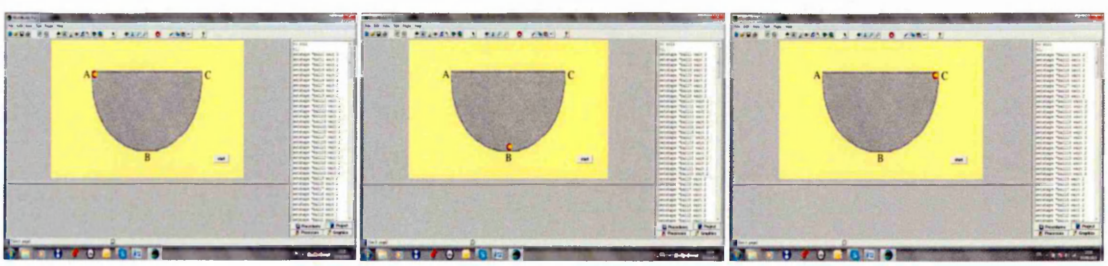


Figure 4.6: Snapshots of Page 1 of simulation *Sim 3*.

The teacher asks the students to recall the key elements of energy theory introduced in Lesson 1 through an INTERACTIVE/AUTHORITATIVE approach by posing the following questions:

'Describe the changes which you observed to occur in the simulation. Can you use the energy concept to interpret in detail these changes?'

Here, the use of 'interactive/authoritative' class of communicative approach is considered as appropriate since the teacher aims for reaching a specific point of view, the scientific view; that is, the use of the store and transfer aspects by the students for the interpretation of the event of the simulation in terms of energy, introduced in Lesson 1.

Then, the teacher presents Page 2 of simulation *Sim3* and asks the students to study it carefully.

Page 2 presents the ball to execute its frictionless motion from the upper point A of the vessel to the other upper point C again and again, as it is illustrated in the snapshots of Figure 4.7.

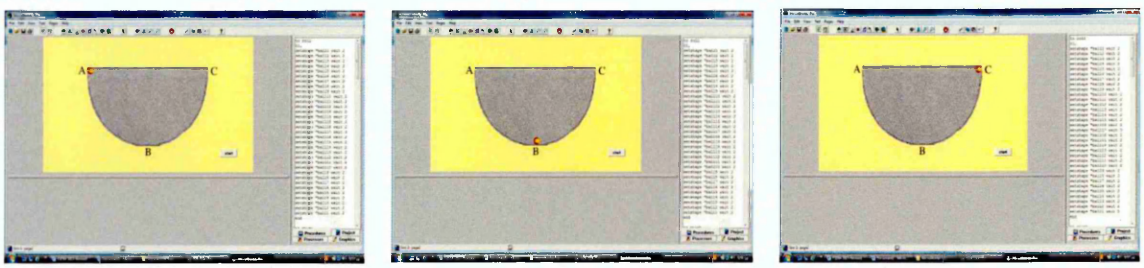


Figure 4.7: Snapshots of Page 2 of simulation *Sim 3*.

At this point, the teacher collects students' initial ideas about the aspect of conservation of energy through an INTERACTIVE/DIALOGIC approach by posing the following question:

'As we see, the ball repeats exactly the same motion. As we also notice, the ball stops instantly at points A and C. Is there any amount of energy stored in the system at these points?'

The 'interactive/dialogic' approach is considered as appropriate since the teacher seeks to explore students' ideas on a specific scientific point of view, namely, the aspect of conservation of energy.

Some of the students will claim that there is no energy stored in the system at points A and C. Then, the teacher will take the opportunity for further probing and poses the following question:

'OK. If there is no energy stored in the system at points A and C, how can you interpret the fact that the ball repeats its motion over and over?

The teacher reviews the students' ideas through a NON INTERACTIVE/DIALOGIC approach.

Since that at this point, the teacher summarizes the various ideas expressed by the students on the aspect of the conservation of energy, the 'non-interactive/dialogic' class of communicative approach is considered as the appropriate one.

In the following, the teacher presents Page 3 of simulation *Sim3* and asks again the students to study it carefully.

In Page 3, the amount of energy in the gravitational store of the system ball-Earth and in the kinetic store of the ball are shown, as the ball moves from the upper point A of the vessel to the lowest point B and then to the other upper point C. These are illustrated in the snapshots of Figure 4.8.

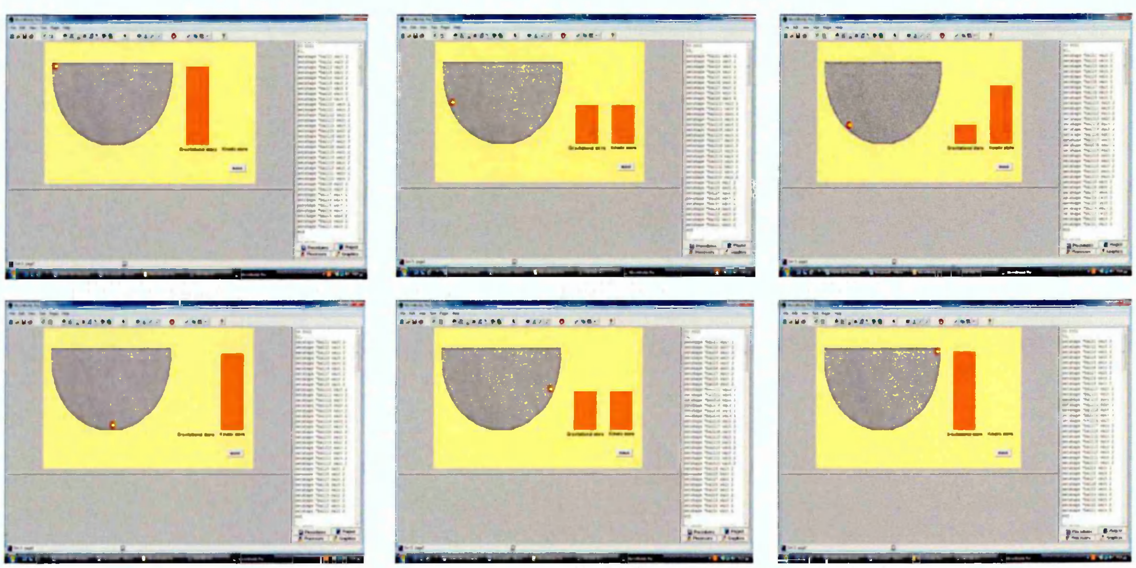


Figure 4.8: Snapshots of Page 3 of simulation *Sim 3*.

Then, through an INTERACTIVE/DIALOGIC approach, the teacher collects the students' conclusions about the amount of energy store of the system by posing the following question:

'What do you conclude about the amount of energy store of the system?'

Once again, the teacher seeks to explore students' views on the aspect of conservation of energy after they studied Page 3 of the simulation. Thus, the kind of talk considered as appropriate is 'interactive/dialogic'.

At this point, the teacher takes a NON INTERACTIVE/AUTHORITATIVE approach and introduces the idea of energy conservation. The teacher might say:

'As most probably all of you concluded, the amount of energy of the system remains constant. Energy is transferred from one store to other different stores but its total amount remains unchangeable. In the case of the simulation you have studied, the energy of the system was initially found in a gravitational store, then it has been transferred along a mechanical working pathway to a kinetic store and again, along a mechanical working pathway to a gravitational store. Due to the fact that the initial amount of energy remains unchangeable, the ball repeats exactly the same motion from point A to point C and the other way round for over and over.

The above conclusion contains one of the key aspects of the concept of energy and a fundamental principle of physics, ***the conservation of energy principle.*** *The conservation of energy principle is formulated as follows:*

When a process takes place in a system, the energy of the system is initially stored in a particular energy store. As the process is integrated, the amount of energy remains the same. The energy of the system is simply stored in other energy stores.'

Here, the teacher presents the scientific point of view, namely the conservation of energy principle, through lecturing and thus the considered as appropriate approach to be used is the 'non interactive/authoritative' approach.

4.9 OVERVIEW OF THE DESIGN AND DEVELOPMENT PROCEDURE OF THE RESEARCH-INFORMED TEACHING SEQUENCE

The reconstructed version was designed and developed according to research evidence-informed designing of science instruction interventions (Scott et al., 2006), presented and discussed in detail in section 4.5, and reformed into an innovative research-informed teaching sequence. In particular, the development of the research-informed teaching sequence included the use of:

- Visual representations: The ideas proposed within the SPT11-14 project (2006, Lawrence, 2007) presented and discussed in detail in Chapter 2 were used.

- Computer simulations: Simulations were created especially for the aims of the proposed teaching sequence in the simulation software Microworlds Pro.

- Interactive teaching approaches: The Communicative Approach (Mortimer and Scott, 2003) presented and discussed in detail in section 4.8 was applied.

Furthermore, the development procedure of the research-informed teaching sequence is illustrated in the diagram of Figure 4.9.

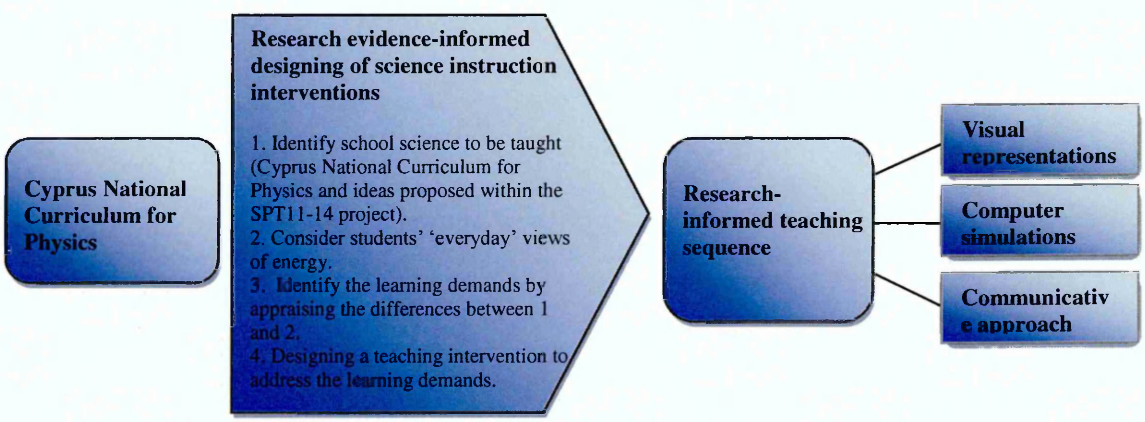


Figure 4.9: Development procedure of the research-informed teaching sequence.

The designing and development of the research-informed teaching sequence began with the development of a plan of its structure. In the development of the structure plan, a series of key issues were taken into consideration. The first concerned the amount of knowledge on energy to be taught; the second, the kind of energy knowledge to be taught; the third, the kind of activities to be included in the lessons and; the fourth, the data collection instruments to be used. The amount of knowledge to be taught, the kind of activities to be included in the lessons and the data collection instruments to be used would define the number of lessons of which the innovative teaching sequence would be consisted whereas the kind of knowledge, the order in which the energy ideas would be introduced.

Regarding the number of lessons, a main concern was that this should be such that conditions of equal treatment, in relation to teaching time, are kept between the experimental and the comparison group. In the current curriculum, the teaching of energy takes place in eight interventions; thus, this would be the teaching time for the comparison group. The second fact concerned the use of communicative approach; some time would be needed for classroom talk to be conducted between the students and between the teacher and the students. Furthermore, for the reasons discussed in a following paragraph, computer simulations would be presented at various points of the lessons to support the instruction of the energy ideas. For these activities to take place, some extra time would be needed which was estimated to be of about 45 minutes, that is, the time of a normal lesson. Then, the third fact concerned the administration of two short-length diagnostic probes, a 15-minute one at the start of the fourth lesson and a 20-minute one at the start of the ninth lesson. The rationale used for the decisions made about the determination of the number, the content, the duration and the appropriate time for administering the short-length diagnostic probes is discussed in detail in section 3.5.1.1. The time needed for conducting the probes plus the time needed for their administration and collection in the experimental group was estimated to be that of another 45-minute normal lesson.

Taking into consideration all the above, it was decided that the innovative teaching intervention be consisted of ten lessons. In addition, the time of two more lessons would be needed for the administration of pre and post-test respectively. Moreover, the structure plan of the innovative teaching sequence is briefly presented in the diagram of Figure 4.10.

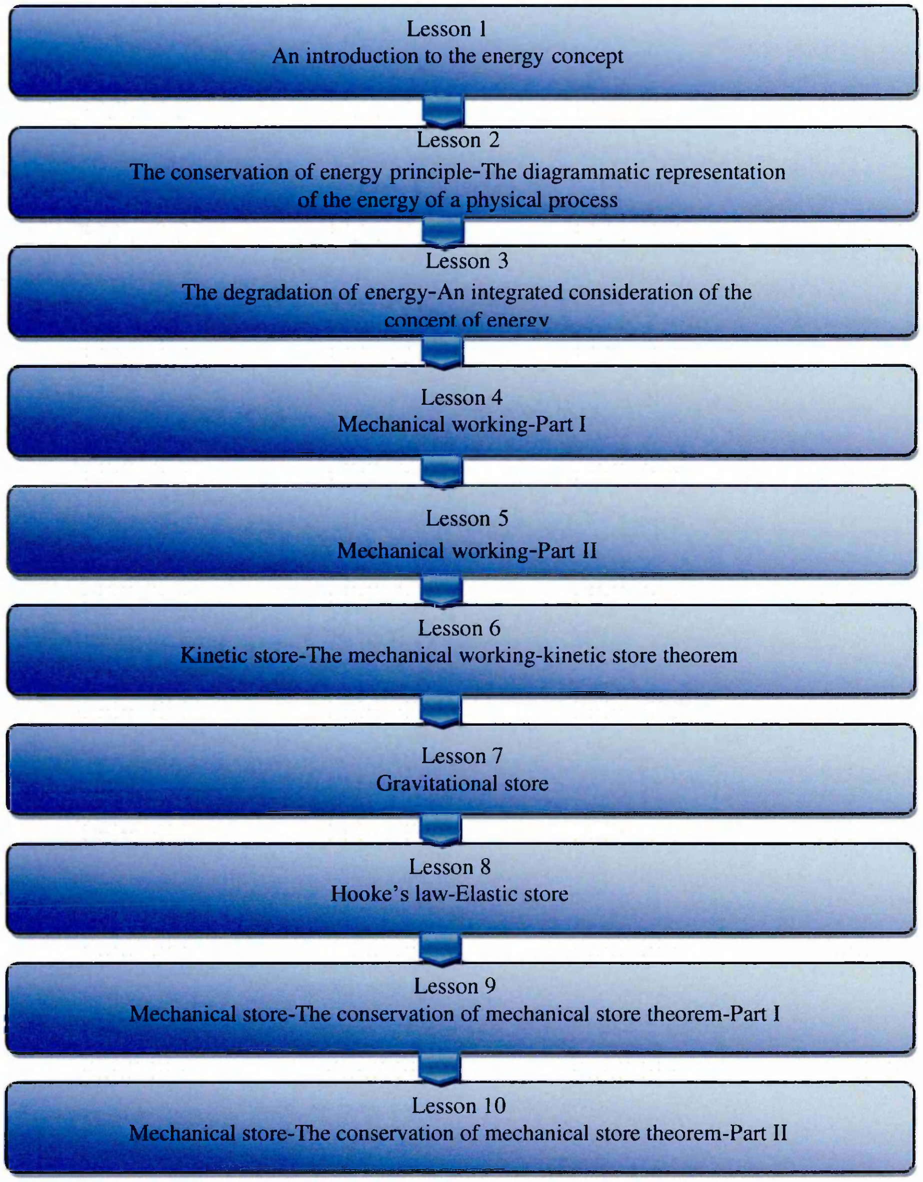


Figure 4.10: Structure of the research-informed teaching sequence.

For comparison purposes, the structure plan of the 'normal' sequence for energy is illustrated in the diagram of Figure 4.11.

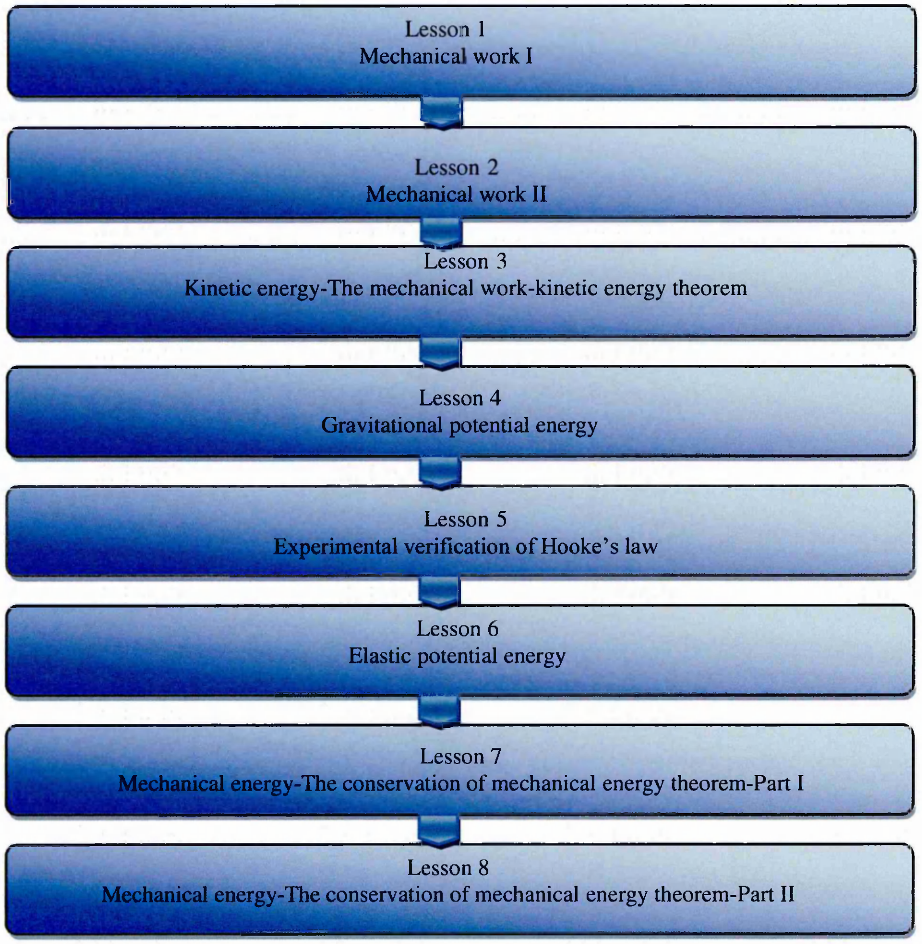


Figure 4.11: Structure of the 'normal' teaching sequence.

Another issue of great importance in the design and development of the research-informed teaching sequence concerned the way the energy knowledge defined by the proposed theoretical framework would be staged. As already discussed in Chapter 1, a main reason for attendant difficulties during the instruction and conceptual understanding of energy is its abstract nature; energy cannot be directly perceived or measured and thus it is not possible for the concept to be made available for the students experimentally. Careful consideration of this issue resulted in deciding that visual means should be used and specifically computer simulations. These were considered as most appropriate visual means compared to images to make available the energy knowledge for the students. This decision was based on a key advantage of computer simulations, that of motion, which was considered as of great importance in promoting understanding of the abstract concept of energy. Specifically, according to the proposed theoretical framework, energy is introduced as an entity which was invented to be used for the interpretation of the changes occurring in a system, as a physical process takes place in it. Due to the advantage of motion, it is possible for a specific process which takes place in a system to be simulated and all occurring changes to be observed, something which a single still image cannot facilitate. Rather, this might be possible by using a set of images illustrating consequent snapshots of a process, a procedure which is considered as time-wasting and maybe less meaningful for the students. Furthermore, within the proposed energy model changes which are observed in a system as a physical process takes place in it, can be described in terms of energy changes, that is, as the emptying of an energy store with the simultaneous filling of other stores, with its total amount to remain constant. As discussed in section 4.7 energy stores are represented with a simple bar notation the height of which indicates the amount of energy stored in them. The emptying and filling of the energy stores can be simulated and visualized with a decrease or increase in the height of the rectangles simultaneously with the corresponding changes occurring in a system, facilitating thus the explicit correlation of the observed physical changes with energy. In particular, this was considered as of crucial importance in introducing and promoting understanding of all four aspects of energy, namely, the aspects of store, transfer, conservation and degradation. Moreover, an example is illustrated in Figure 4.8 in which the snapshots of Page 3 of simulation *Sim 3* present simultaneously the physical and the energy changes which take place in the system vessel-ball. However, it has to be noted that in a few cases, it was considered as appropriate that the energy knowledge be staged through the use of images and simple experimental demonstrations executed by the teacher.

As stated earlier, the series of computer simulations were created in the simulation environment Microworlds Pro. This particular simulation software was selected from those available for two main reasons: firstly, it enables, from a technological point of view, the simulation of suitable processes and features for the instruction of the energy concept in carefully selected systems; secondly, it enables the manipulation of the simulations by both the teacher and the students without any training prior to their study since its use is very simple. As mentioned above, a series of images were also created and furthermore, a short PowerPoint presentation which included the specific energy stores and transfer pathways to be introduced.

A second and equally important issue in staging the energy knowledge concerned the order in which the energy ideas would be introduced to the students. Consideration resulted in deciding that the introduction and qualitative treatment of the proposed energy model would take place first and be followed by the quantitative treatment. In particular, the first three of the ten-lesson teaching sequence included the introduction of all four aspects of the energy concept, namely, store, transfer, conservation and degradation and their use in describing both verbally and diagrammatically the changes occurring in various physical systems. Furthermore, in the remaining seven lessons the specific energy stores defined by the curriculum, namely, kinetic, gravitational, elastic and mechanical store, and the specific transfer pathways, mechanical, heating and sound, would be further elaborated qualitatively and mathematically treated.

In addition to staging the energy knowledge, considerations were made on supporting student internalization of the specific ideas introduced. It was decided that opportunities should be provided to the students to try out the new ideas through discussions both with the teacher and between them and also through short written tasks to be done during the lessons either individually or collaboratively, included in worksheets especially developed for each lesson.

Following the phase of supporting student internalization, considerations were made on handing-over to the students the responsibility of energy learning. It was decided that opportunities should be provided to the students to talk through their developing understanding through specific tasks on novel contexts included in the worksheets. These tasks could either assigned to be done and then discussed during the lessons or assigned as homework and discussed in the next lesson. Furthermore, handing-over could provide the teacher with opportunities to monitor students' progress in understanding the energy ideas introduced and intervene during discussions to scaffold understanding.

The creation of the visual material was followed by the development of the written material addressed to both the teacher and the students. Regarding the material for the students, this included a series of ten detailed handouts and the corresponding worksheets mentioned above. Furthermore, the material for the teacher included a series of ten detailed lesson plans and the correct answer sheets for the corresponding ten worksheets.

The development of the written material for both the teacher and the students was completed in four sub-stages: in the first sub-stage, the material for the first three lessons was developed and much attention was placed on it since these lessons constitute the core of the teaching sequence in which all the energy ideas are introduced. Then, the development of the material for the two lessons concerning mechanical working took place followed by that of the three lessons concerning kinetic, gravitational and elastic store. In the fourth and last sub-stage, the material for the two lessons concerning mechanical store and the conservation of mechanical store theorem was developed.

The written material and the PowerPoint presentation were translated into Greek. Furthermore, the first phase completed with the preparation of a full set of the teaching material for the experimental teacher. This included a CD with the simulations, the PowerPoint presentation and the images and also the Greek version of the written material in which an introductory part was included within which the rationale and the theoretical framework of the research-informed teaching sequence, the students' alternative interpretations about energy and the communicative approach were briefly presented (The English version is illustrated in Appendix X). The full set of the teaching material was sent to the experimental teacher about two weeks prior to the start of the educational experiment. Also, about a week prior to the start, the researcher had a meeting with the teacher in which issues arose by the teacher concerning the instruction of various aspects of the research-informed materials were discussed in some detail.

4.10 THE DESIGN BRIEF WHICH THE TEACHING SEQUENCE ADDRESSED

This section deals with the development of the innovative research-informed teaching sequence for the instruction of the energy concept according to evidence-informed approach. The application of each of four steps included in the evidence-informed approach was drawn upon the example of an approach developed for the instruction of simple electric circuits by Scott et al. (2006).

4.10.1 SCHOOL SCIENCE KNOWLEDGE TO BE TAUGHT

The content of school science knowledge to be taught includes the theoretical framework proposed in this doctoral thesis presented and discussed in section 4.7. Furthermore, the school science knowledge to be taught involves the development of a model in which energy:

a. is an abstract, mathematical idea;
b. is a property of systems which is related to four key aspects;
c. can be found in various kinds of stores which can be emptied or filled;
d. can be transferred from one store to another (or others) along different transfer pathways;
e. can be conserved;
f. can be degraded;
g. can be used for the description of the changes which are observed in a range of physical systems, as a process is progressing in them.

Furthermore, emphasis should be placed on:

h. the concept of a system;
i. the concept of mechanical working in the case of a constant force;
j. the concept of mechanical working in the case of a variable force whose direction is constant;
k. the concept of kinetic store;
l. the mechanical working-kinetic store theorem;
m. the concept of gravitational store;
n. the concept of elastic store;
o. the concept of mechanical store;
p. the conservation of mechanical store theorem.

4.10.2 STUDENTS' 'EVERYDAY' VIEWS ABOUT ENERGY AND RELATED PROCEDURES

Findings reported in the international science education literature as well those from a study within the researcher's Master's dissertation presented and critically discussed in Chapter 2 revealed that students hold the following alternative conceptions on the specific energy knowledge defined by the curriculum:

1. there is a confusion between the concepts of 'energy' and 'force'. Students use the word 'energy' as synonymous of the word 'force' and the other way round (Ault et al., 1988, Gilbert and Pope, 1982, Kruger, 1990, Orfanidou, 2007, Watts and Gilbert, 1983);
2. they consider that force can be converted into energy and the other way round. Students distinguish the concepts of 'energy' and 'force' but they consider them as interconnected (Orfanidou, 2007, Watts & Gilbert, 1983);
3. they consider 'pressure' as being stored in a compressed spring instead of energy in an elastic store (Orfanidou, 2007);
4. they consider movement as energy (Watts and Gilbert, 1983);
5. they relate movement and activity with energy. Students consider that there isn't energy in the cases in which there isn't any kind of movement or activity (Solomon, 1983a, Stead, 1980, Watts and Gilbert, 1983, Watts, 1983a);
6. there is a confusion between the concepts of 'energy' and 'speed'. Students use the word 'speed' as synonymous of the word 'energy' and the other way round (Orfanidou, 2007);
7. they consider that energy can be flow-transferred from one place of a system into another (Duit, 1981, Gayford, 1986, Orfanidou, 2007, Watts & Gilbert, 1985);
8. they consider that energy is 'released' from the place of the system in which it is stored (Orfanidou, 2007);
9. they consider that energy 'disappears' or 'stops to exist (Orfanidou, 2007) or 'is consumed' (Ault et al., 1988) at the end;
10. they consider that whenever there is an energy transfer, mechanical working is done (Goldring and Osborne, 1994);
11. they consider that mechanical working 'produces' force (Goldring and Osborne, 1994);
12. they consider that there is heating whenever mechanical working is done (Goldring and Osborne, 1994);

13. they consider that mechanical working done by the weight of an object (or the force exerted by a worker on an object) as proportional to the effort made by the worker when lifting up the object (Orfanidou, 2007);
14. they consider that mechanical working done by the weight of an object (or by another force exerted on the object), during its movement from one vertical position to another, depends on the path followed by the object between the two positions (Orfanidou, 2007);
15. they consider that the amount of energy in the kinetic store of a moving object does not depend on its speed (Kruger, 1990);
16. they consider that the amount of energy in a of gravitational store of the system object-Earth is proportional to the effort made by a worker when lifting up the object (Orfanidou, 2007);
17. they consider that the amount of energy in a of gravitational store of the system object-Earth depends on the path followed by the object when moving from its initial to its final vertical position (Orfanidou, 2007);
18. they consider that energy is stored only in a gravitational store of the system object-Earth during the vertical movement of an object (Orfanidou, 2007).

4.10.3 LEARNING DEMANDS

Each of the following learning demands involves identifying a difference between school knowledge to be taught (list in section 4.10.1) and students' 'everyday' views. For each demand the relevant school knowledge to be taught and the everyday view(s) are indicated in parentheses. Learning in the area of energy procedures involves the students in coming to:

- develop the concept of energy as an abstract calculable quantity which can be used in the description of the observed changes in a range of systems and not be confused or interconnected with other physical quantities such as 'force', 'movement' or 'speed'(a, g-1, 2, 4, 5, 6);
- develop the idea that energy, is an abstract quantity, a property of systems, which can be stored in stores and transferred from one store in another along pathways and not a

substance-like quantity which is 'flow-transferred' from one part of a system to another or 'released' from a part of a system (a, b, c, d, h-7, 8);

- develop the idea that energy is a conserved quantity and thus, it does not 'disappear'/'stop to exist'/'consumed' at the end of a physical process. Energy can be transferred along various pathways and stored in different energy stores with its amount to remain constant (e-9);
- develop the idea that energy is a degraded quantity and thus, it does not 'disappear'/'stop to exist'/'consumed' at the end of a physical process; rather, it can be stored in internal stores and cannot be further used (f-9);
- understand that energy can be transferred along various transfer pathways and not only along a mechanical working pathway; furthermore, the transfer of energy along a mechanical working pathway does not prerequisites a transfer along a heating pathway (d-10, 12);
- understand that mechanical working is a mechanism of transferring energy, the amount of which is proportional to:
  i. the magnitude of the exerted force
  ii. the displacement in the position of the object, caused by the force.
  Furthermore, mechanical working does not 'produce' force (i, j-11);
- understand that mechanical working done by the weight of an object (or by a force exerted on the object) does not depend on:
  i. the path followed by the object when it moves between two vertical positions
  ii. the effort made by a worker when lifting up an object (i, j- 11, 13, 14);
- understand that when an object moves, there is energy in a Kinetic store. The amount of energy in the kinetic store of a moving object is directly proportional to:
  i. its mass
  ii. the square of the magnitude of its velocity (k, l-15);
- understand that when an object which is within the Earth's gravitational field is lifted up between two vertical positions, there is energy in a gravitational store of the system object-Earth, the amount of which is proportional to:
  i. the mass of the object
  ii. the distance between the two vertical positions.

Moreover, the amount of energy in a gravitational store does not depend on:

   i. the path followed by the object when it moves between two vertical positions
   ii. the effort made by a worker when lifting up an object (m-16, 17);

- understand that when a spring (or any other elastic object) is deformed (stretched or compressed) there is energy in an Elastic store. Furthermore, there is not 'pressure' stored in a deformed spring (or in another elastic object) but rather an amount of energy in the elastic store of the spring (n-3);
- understand that when an object moves vertically, downwards or upwards, there is energy in the gravitational store of the system object-Earth **and** the kinetic store of the object the sum of which is called mechanical store; furthermore, mechanical store is conserved under ideal conditions (o, p-18).

4.10.4 DESIGN OF TEACHING INTERVENTION

a. Teaching goals

The teaching goals are formulated as follows:

To build on the ideas that:

- changes observed in a range of physical systems can be described in terms of energy;
- all parts of a physical system are necessary in order the observed changes to occur;
- energy is a property of systems related to four key aspects;
- energy is stored within a physical system in various kinds of stores which can be filled or emptied;
- energy is transferred within a physical system from one store to another along various kinds of transfer pathways;
- energy is conserved;
- energy is degraded.

To introduce, and support the development of, the ideas that:

- a moving object has energy in a Kinetic store;

- when an object is at a raised position above the centre of Earth or some other reference point, there is energy in a Gravitational store of the system object-Earth;
- a deformed (stretched or compressed) elastic object has energy in an Elastic store;
- when a chemical reaction between two substances occurs (for example fuel and oxygen), there is energy in a Chemical store of the system reactant-reactant, due to the kinds of bonds between the atoms or molecules which consist the reactants;
- a solid, a liquid or a gas has energy in an Internal store. Internal store is consisted of two parts: the energy because of the continuous motion (kinetic store) of the particles (atoms, molecules) from which an object or a substance is made up and, the energy of the chemical bonds between the atoms or the molecules;
- the sum of the Gravitational store of the system object-Earth and the Kinetic store of an object which moves freely in a downward or an upward direction is called Mechanical store;
- mechanical working is the mechanism with which an amount of energy is transferred from one store to another when a force is exerted on an object which is initially at rest and causes its displacement;
- when two objects or substances of different temperature are in contact, then energy is transferred along a heating pathway. The amount of energy which is transferred along a heating pathway is stored in an internal store;
- when a cause (for example, the clap of hands, the knock on a door) set the particles (atoms, molecules) which consist an object or a substance into vibration, then energy is transferred along a sound pathway. The amount of energy which is transferred along a sound pathway is stored in an internal store;
- a physical description is a verbal description of the changes observed in a system in the natural world, as a physical process takes place in it;
- an energy description is a verbal and diagrammatical description of the changes observed in a system as a physical process takes place in it, expressed in terms of energy;
- the amount of energy in the energy stores can be represented with a simple bar notation. Changes in the amount of energy in an energy store can be represented with an increase or a decrease of the height of the bar;

- transfer pathways can be represented with the simple notation of an arrow. The direction of the arrow defines the direction of the energy transfer whereas the thickness of the arrow visualizes the amount of energy being transferred from one energy store to another.

To draw attention to, and to emphasize, the ideas that:

- changes observed in a system can be described diagrammatically in terms of energy with both a Sankey Diagram and a Full Sequence Energy Diagram;
- the difference in the initial and the final amount of energy in the kinetic store of an object on which a resultant force acts and causes its displacement, equals the amount of energy being transferred along a mechanical working pathway done by the resultant force. This is known as the mechanical working-kinetic store theorem;
- the amount of energy being stored in the gravitational store of the system object-Earth equals the amount of energy being transferred along a mechanical working pathway done by a force which is exerted on the object to be placed at a raised position above the centre of Earth or some other reference point;
- the positive, negative or zero value of mechanical working done by a force which acts on an object can be interpreted in terms of energy transfer from one store into another;
- mechanical working done by the weight of an object does not depend on the path followed by the object when moving from an initial to a final vertical position, rather on the vertical distance between the two positions;
- mechanical working done by the weight of an object (or the force exerted on the object by a worker) does not depend on the effort made when lifting up the weight;
- the amount of energy in a gravitational store of the system object-Earth does not depend on the path followed by the object when moving from an initial to a final vertical position, rather on the vertical distance between the two positions;
- the amount of energy in a gravitational store of the system object-Earth does not depend on the effort made by a worker when lifting up the object;

- the amount of energy in the elastic store of a deformed spring equals the amount of energy being transferred along a mechanical working pathway done by a force of the form F=k.x (Hooke's law) which acts on the spring and causes the deformation;
- the amount of energy in a mechanical store is conserved only under certain conditions; this is known as the conservation of mechanical store theorem.

To develop the ability to:

- specify the parts of a physical system;
- formulate a physical description of the changes observed in a system;
- formulate a verbal energy description of the changes observed in a system;
- draw the Sankey diagram and the Full Sequence Energy Diagram of a system;
- calculate mechanical working done by a constant force;
- calculate mechanical working done by a variable force whose direction is constant, using the graph F=f(x);
- calculate the amount of energy in the kinetic store of a moving object;
- apply the mechanical working-kinetic store theorem to solve quantitative energy problems;
- calculate the amount of energy in the gravitational store of the system object-Earth when the object is at a raised position;
- calculate the amount of energy in the elastic store of a deformed spring or other elastic object;
- apply the conservation of mechanical store theorem to solve qualitative and quantitative energy problems.

b. Plan of the sequence of teaching activities

The teaching intervention consisted of ten lessons designed to address the above teaching goals.

Pre-testing

Prior to the start of the teaching intervention, pre-test administered to the students aiming to collect their initial views on the concept of energy.

Lesson 1

The learning demands addressed in this lesson are:

- develop the concept of energy as an abstract calculable quantity which can be used in the description of the observed changes in a range of systems and not be confused or interconnected with other physical quantities such as 'force', 'movement' or 'speed';
- develop the idea that energy, is an abstract quantity, a property of systems, which can be stored in stores and transferred from one store in another along pathways and not a substance-like quantity which is 'flow-transferred' from one part of a system to another or 'released' from a part of a system.

The teaching goals which address the learning demands are:

To build on the ideas that:

- changes observed in a range of physical systems can be described in terms of energy;
- all parts of a physical system are necessary in order the observed changes to occur;
- energy is a property of systems related to four key aspects;
- energy is stored within a physical system in various kinds of stores which can be filled or emptied.

To introduce, and support the development of, the ideas that:

- a moving object has energy in a Kinetic store;
- when an object is at a raised position above the centre of Earth or some other reference point, there is energy in a Gravitational store of the system object-Earth;
- a deformed (stretched or compressed) elastic object has energy in an Elastic store;
- when a chemical reaction between two substances occurs (for example fuel and oxygen), there is energy in a Chemical store of the system reactant-reactant, due to the kinds of bonds between the atoms or molecules which consist the reactants;
- a solid, a liquid or a gas has energy in an Internal store. Internal store is consisted of two parts: the energy because of the continuous motion (kinetic store) of the particles (atoms, molecules) from which an object or a substance is made up and, the energy of the chemical bonds between the atoms or the molecules;
- mechanical working is the mechanism with which an amount of energy is transferred from one store to another when a force is exerted on an object which is initially at rest and causes its displacement;
- when two objects or substances of different temperature are in contact, then energy is transferred along a heating pathway;
- when a cause (for example, the clap of hands, the knock on a door) set the particles (atoms, molecules) which consist an object or a substance into vibration, then energy is transferred along a sound pathway;
- a physical description is a verbal description of the changes observed in a system in the natural world, as a physical process takes place in it;
- an energy description is a verbal and diagrammatical description of the changes observed in a system as a physical process takes place in it, expressed in terms of energy.

To develop the ability to:

- specify the parts of a physical system;
- formulate a physical description of the changes observed in a system;
- formulate a verbal energy description of the changes observed in a system.

In order to stage for the class the energy knowledge defined by the teaching goals, the teacher presents two simulations. The first one illustrates a ball rolling from the top of a curved surface down to a horizontal plane. At the bottom of the curved surface, it hits a second ball and comes to rest whereas the second ball is set up into a uniform motion on the horizontal plane. The second simulation illustrates a spring on a horizontal plane on which a hand acts and causes its compression. The simulations were designed to challenge the students' thinking about: (i) the necessary set of objects in order the observed changes to occur and, (ii) how the observed changes in the system of each simulation could be interpreted in terms of a common physical quantity and furthermore, in terms of energy.
Then, the teacher elicits and explores the students' views by asking them to: (i) describe in detail the event of each simulation, (ii) state which objects included in each simulation are necessary in order the changes to occur and, (iii) to formulate an interpretation for the changes observed in each simulation. The teacher engages the class in a brainstorming activity and writes all the ideas expressed on the whiteboard. She then reviews the students' views and introduces the definition of a physical system, emphasizing the surrounding air and the ground as being parts of the systems studied. Afterwards, she leads the students' thoughts on the idea that energy is a property of the systems. At this point, the teacher introduces the ideas of energy stores and transfer pathways and presents the various kinds of energy stores using a sequence of simulations as well as the various kinds of transfer pathways using a short PowerPoint presentation. Then, she proceeds to the introduction of the idea that the observed changes can be described in terms of energy, that is, changes are occurred when an energy store is emptied and at the same time some others are filled with energy being transferred along various transfer pathways.

At this point, the teacher presents the simulations once again aiming to support student internalization of the ideas introduced. She provides the students with the opportunity to try out these new ideas by asking them to describe the changes they observe in each simulation one in terms of energy.

In concluding the lesson, the teacher hands-over the responsibility of learning to the students. She provides the students with the opportunity to try out the ideas staged in novel situations included in a worksheet, both in class working collaboratively and home.

Lesson 2

The learning demand addressed in this lesson is:

- develop the idea that energy is a conserved quantity and thus, it does not 'disappear'/'stop to exist'/'consumed' at the end of a physical process. Energy can be transferred along various pathways and stored in different energy stores with its amount to remain constant.

The teaching goals which address the learning demand are:

To build on the idea that:
- energy is conserved.

To introduce, and support the development of, the ideas that:
- a physical description is a verbal description of the changes observed in a system in the natural world, as a physical process takes place in it;
- an energy description is a verbal and diagrammatical description of the changes observed in a system as a physical process takes place in it, expressed in terms of energy;
- the amount of energy in the energy stores can be represented with a simple bar notation. Changes in the amount of energy in an energy store can be represented with an increase or a decrease of the height of the bar;
- transfer pathways can be represented with the simple notation of an arrow. The direction of the arrow defines the direction of the energy transfer whereas the thickness of the arrow visualizes the amount of energy being transferred from one energy store to another.

To draw attention to, and to emphasize, the ideas that:
- changes observed in a system can be described diagrammatically in terms of energy with both a Sankey Diagram and a Full Sequence Energy Diagram.

To develop the ability to:
- formulate a physical description of the changes observed in a system;
- formulate a verbal energy description of the changes observed in a system;
- draw the Sankey diagram and the Full Sequence Energy Diagram of a system.

The teacher stages for the class the conservation of energy aspect by presenting the first page of a simulation which illustrates a ball starting to roll from the upper point of a semi-spherical vessel down to the bottom and then up to the other point where it instantly stops. Hence, it rolls again to the bottom of the vessel and finally up to the upper point from where it started. This simulation was designed to challenge the students' thinking of energy as a conserved quantity.

The teacher supports student internalization of the energy knowledge staged at Lesson 1 by asking them to recall it and formulate an energy description of the event of the simulation.

Then, the teacher presents the second page of the simulation which illustrates the ball executing the same motion endlessly. Afterwards, she elicits and explores the students' ideas on the conservation of energy aspect by asking them to express their views about the amount of energy of the system. In particular, she focuses the discussion on the upper points of the course of the ball, where it stops moving instantaneously, and asks the students to express their point of view as to whether there is energy in the system at these points or not. Hence, the teacher reviews the students' views and proceeds to the presentation of the third page of the simulation in which the emptying and filling of the gravitational and kinetic stores and thus, the conservation of the energy of the system is illustrated, as the ball moves form one upper point to the other. In the following, the teacher supports student internalization by asking them to express a conclusion about the amount of energy of the system. At this point, she addresses the idea that the amount of energy store of the system does not 'disappear' or 'stops to exist' at any point, but remains constant, or in other words the energy of the system is conserved.

The teacher continues with the introduction of the Sankey Diagram. She addresses the idea that the changes observed in a physical system could be described in terms of energy not only verbally but also diagrammatically and introduces the main criteria a Sankey Diagram should fulfill. Then, the teacher presents another simulation which illustrates a worker lifting up a heavy box using a frictionless pulley. At this point the teacher hands-over the responsibility of learning and provides the students with the opportunity to try out the new ideas in novel situations by asking them to formulate an energy description of the event of the new simulation and also express this diagrammatically with a Sankey Diagram. Then, the teacher proceeds to the introduction of the Full Sequence Energy Diagram.

The teacher further hands-over responsibility of learning the energy knowledge staged by assigning the tasks included in the relevant worksheet.

Lesson 3

The learning demand addressed in this lesson is:

- develop the idea that energy is a degraded quantity and thus, it does not 'disappear'/'stop to exist'/'consumed' at the end of a physical process; rather, it can be stored in internal stores and cannot be further used.

The teaching goals which address the learning demand is:

To build on the ideas that:

- energy is conserved;
- energy is degraded.

To introduce, and support the development of, the ideas that:

- when two objects or substances of different temperature are in contact, then energy is transferred along a heating pathway;
- when a cause (for example, the clap of hands, the knock on a door) set the particles (atoms, molecules) which consist an object or a substance into vibration, then energy is transferred along a sound pathway.
- the amount of energy which is transferred along a heating or a sound pathway is stored in an internal store and cannot be further used.

The teacher presents Page 2 of the simulation used in Lesson 2 for the introduction of the conservation aspect of energy. Then, she supports students internalization by asking them to recall the idea of conservation of energy and to interpret in terms of energy the repeated motion of the ball.

In order for the teacher to stage the degradation aspect of energy she presents a new simulation which illustrates the same system ball-semi-spherical vessel. In this simulation, the ball is illustrated to roll down from an upper point and gradually reach a reduced height each time until it reaches the bottom of the vessel where it finally stops. Afterwards, the teacher elicits and explores the students' views on the degradation aspect by asking them to interpret in terms of energy the behavior of the system. In the following, she reviews the students' views and proceeds to the introduction of the idea of the degradation of energy.

The teacher continues with the presentation of another simulation which illustrates an orange falling freely from the tree to the ground. This simulation was designed to stage the heating and sound pathways along which the energy of a system is degraded in the internal stores. The teacher supports student internalization by asking them to formulate a verbal description and represent the event of the simulation diagrammatically using a Full Sequence Energy Description. Then, she focuses the discussion on the sound pathway along which the energy of the system can also be degraded.

At this point, the teacher hands-over responsibility of learning to students by asking them to try out working collaboratively in class, the ideas staged to novel situations included in the tasks of the relevant worksheet.

Lesson 4

The learning demands addressed in this lesson are:

- understand that mechanical working is a mechanism of transferring energy, the amount of which is proportional to:
  iii. the magnitude of the exerted force
  iv. the displacement in the position of the object, caused by the force.
  Furthermore, mechanical working does not 'produce' force;
- understand that energy can be transferred along various transfer pathways and not only along a mechanical working pathway; furthermore, the transfer of energy along a mechanical working pathway does not prerequisites a transfer along a heating pathway.

The teaching goals which address the learning demands are:

To introduce, and support the development of, the idea that: • mechanical working is the mechanism with which an amount of energy is transferred from one store to another when a force is exerted on an object which is initially at rest and causes its displacement. To draw attention to, and to emphasize, the idea that: • the positive, negative or zero value of mechanical working done by a force which acts on an object can be interpreted in terms of energy transfer from one store into another. To develop the ability to: • calculate mechanical working done by a constant force.

The teacher administers a 15-minute short-length diagnostic test aimed to probe the students' understanding on the energy ideas introduced in the first three lessons of the teaching intervention.

The teacher stages for the class the idea of mechanical working by presenting an image which illustrates a skating teacher teaching a young skater boy by exerting on it a constant horizontal force. Specifically, the image was created to focus the students' thinking on the idea that mechanical working done by a constant force is the mechanism of energy transfer when the force acts on an object, initially at rest, and causes its displacement in the direction of the force.

In supporting student internalization, the teacher asks the students to make an energy description of the event of the image recalling thus the ideas of energy stores and energy transfer along a mechanical working pathway. Then, the teacher reviews the students' views and introduces the definition and the mathematical formula of mechanical working done by a constant force in the direction of displacement. At this point, she emphasizes the proportionality relation between mechanical working and the magnitude of the force and the displacement in position caused by the force.

The teacher then proceeds to the introduction of the general formula of mechanical working, that is, of mechanical working done by a constant force of any direction. The teacher further supports student internalization by engaging them in a discussion concerning various directions of force such as at 90° and 180° and derives the corresponding formulae. Furthermore, she takes the opportunity to hand-over responsibility of learning of the idea of mechanical working to students through discussion on the cases at which mechanical working takes positive, negative or zero value by asking the students to interpret these values of mechanical working in terms of energy transfer.

Lesson 5

The learning demands addressed in this lesson are:

- understand that mechanical working is a mechanism of transferring energy, the amount of which is proportional to:
  - v. the magnitude of the exerted force
  - vi. the displacement in the position of the object, caused by the force;

- understand that mechanical working done by the weight of an object (or by a force exerted on the object) does not depend on:
  - i. the path followed by the object when it moves between two vertical positions
  - ii. the effort made by a worker when lifting up an object.

The teaching goals which address the learning demands are:

To draw attention to, and to emphasize, the ideas that: • mechanical working done by the weight of an object does not depend on the path followed by the object when moving from an initial to a final vertical position, rather on the vertical distance between the two positions; • mechanical working done by the weight of an object (or the force exerted on the object by a worker) does not depend on the effort made when lifting up the weight. To develop the ability to: • calculate mechanical working done by a variable force whose direction is constant, using the graph F=f(x).

In order to stage for the class the energy knowledge defined by the above teaching goals, the teacher presents an image in which a ball is illustrated to: (i) fall freely, (ii) roll on an inclined plane, (iii) roll on a curved surface and, (iv) move down the stairs from the same height. Then, the teacher provides the students with the information that the movement of the ball in the air, on the inclined plane, the curved surface and the stairs is considered as frictionless. In particular, this image was created to challenge the students' thinking on the idea that the value of mechanical working done by a constant force or an object's weight does not depend on the path followed from an initial to a final position, rather on the vertical distance between them. Hence, the teacher elicits and explores the students' views by engaging them in an exchange of ideas by asking them to compare mechanical working done by the ball's weight in each of four systems. At this point, the teacher summarizes the different points of view and then presents the correct answer.

In the following, the teacher turns the focus of the lesson on the idea that the general formula $W=F.x.\cos\theta$ is valid only in the case of mechanical working done by a force of constant magnitude and proceeds to the introduction of the idea that mechanical working done by a force of variable magnitude can be calculated by the area under the graph F=f(x).

Concluding the lesson, the teacher hand-over responsibility of learning to students by asking them to try out the ideas on mechanical working staged to novel situations included in the tasks of the relevant worksheet.

Lesson 6

The learning demand addressed in this lesson is:

- understand that when an object moves, there is energy in a kinetic store. The amount of energy in the kinetic store of a moving object is directly proportional to:
  i. its mass
  ii. the square of the magnitude of its velocity.

The teaching goals which address the learning demand are:

To introduce, and support the development of, the idea that: • a moving object has energy in a Kinetic store. To draw attention to, and to emphasize, the idea that: • the difference in the initial and the final amount of energy in the kinetic store of an object on which a resultant force acts and causes its displacement, equals the amount of energy being transferred along a mechanical working pathway done by the resultant force. This is known as the mechanical working-kinetic store theorem. To develop the ability to: • calculate the amount of energy in the kinetic store of a moving object; • apply the mechanical working-kinetic store theorem to solve quantitative energy problems.

The teacher initiates the lesson by asking the students to recall the idea of kinetic store. Then, in order to stage for the class the energy knowledge defined by the teaching goals she presents a simulation in which a worker is illustrated to roll a few pieces of office equipment along a smooth corridor applying a constant force. She provides the students with the information that air resistance is negligible to be taken into consideration and the rolling of the office equipment on the smooth corridor is frictionless. Specifically, this simulation was designed to focus the students' thinking on: (i) the idea that the amount of energy in the kinetic store of a moving object is directly proportional to its mass and the square of the magnitude of its velocity and, (ii) the equality relation between the amount of energy being transferred along a mechanical working pathway and the change in the amount of energy in the kinetic store of an object, which expresses the mechanical working-kinetic store theorem.

In the following, the teacher proceeds to the verification of the formulae of the amount of energy in a kinetic store and the mechanical working-kinetic store theorem. For supporting student internalization, the teacher addresses a sequence of leading questions to the class such as: (i) Can you make the energy description of the event of the simulation?, (ii) Can you draw the Sankey diagram of the system?, (iii) Compare the amount of energy being transferred along mechanical working pathway and the amount of energy stored in the kinetic store of the office equipment , (iv) Which formula applies for the calculation of mechanical working done by the force exerted by the worker on the office equipment and why?, (v) 'If it is assumed that the office equipment is of mass m, which fundamental law is valid in this case and which formula describes it?, (vi) What kind of motion does the office equipment and which mathematical formulae describe its motion? Then, the teacher performs the mathematical calculations and verifies the formula.

At this point, the teacher hand-over responsibility of learning of the ideas staged to students by assigning them the tasks included in the relevant worksheet as homework.

Lesson 7

The learning demand addressed in this lesson is:

- understand that when an object which is within the Earth's gravitational field is lifted up between two vertical positions, there is energy in a gravitational store of the system object-Earth, the amount of which is proportional to:
  iii. the mass of the object
  iv. the distance between the two vertical positions.

Moreover, the amount of energy in a gravitational store does not depend on:
  iii. the path followed by the object when it moves between two vertical positions
  iv. the effort made by a worker when lifting up an object.

The teaching goals which address the learning demand are:

> To introduce, and support the development of, the idea that:
> - when an object is at a raised position above the centre of Earth or some other reference point, there is energy in a Gravitational store of the system object-Earth.
>
> To draw attention to, and to emphasize, the idea that:
> - the amount of energy being stored in the gravitational store of the system object-Earth equals the amount of energy being transferred along a mechanical working pathway done by a force which is exerted on the object to be placed at a raised position above the centre of Earth or some other reference point.

The teacher asks the students to recall the idea of gravitational store. In order for the teacher to stage for the class the energy knowledge defined by the teaching goals, she raises a small metallic ball and leaves it to fall freely to the floor. Then, the teacher elicits and explores the students' views by asking them to explain why that happens. In particular, the purpose of this activity is to focus the students' thinking on the idea of gravitational force (weight). Hence the teacher summarizes the students' views and introduces the idea that the space around every object with mass like Earth consists a gravitational field. On all objects within the Earth's gravitational field, a gravitational force acts which is called, as they already know, weight.

In staging further, the teacher presents the class with a simulation in which a worker is illustrated to lift a heavy box using a pulley. She provides the students with the information that the worker exerts a constant force on the rope, he lifts the box with a constant speed and that both the movement of the box in the air and the rotation of the pulley can be considered as frictionless. This simulation was designed to challenge the students' thinking on the idea that: (i) the amount of energy in a gravitational store is directly proportional to the mass of the object and the vertical distance moved by the object from an initial to its final position, (ii) the amount of energy being transferred along a mechanical working pathway done by a force which is exerted on the object to be placed at a raised position above the centre of Earth or other point of reference equals the amount of energy stored in the gravitational store of the system object-Earth.

At this point, the teacher initiates the procedure of mathematical verification of the calculating formula of the amount of energy in a gravitational store. She supports student internalization through a sequence of leading questions such as: (i) Can you make the energy description of the event of the simulation?, (ii) Can you draw the Sankey diagram of the system?, (iii) Compare the amount of energy being transferred along a mechanical working pathway and the amount of energy stored in the gravitational store of the system box-Earth, (iv) Which formula applies for the calculation of mechanical working done in this case?, (v) Is any other force exerted on the box?, (vi) Compare the two forces. Then, the teacher performs the mathematical calculations and verifies the formula.

The teacher continues with the presentation of an image which illustrates a man about to ascend to the top of a forested hill where his hotel is located. In order to do so, he can choose to follow either the inclined straight road, the curvy forest path or to use the lift. This image was created to challenge the students' thinking on the idea that the amount of energy in the gravitational store of the system object-Earth does not depend on the path followed from an initial to a final position rather on the vertical distance between them. Then, the teacher elicits and explores the students' views by asking them to compare the amount of energy in the gravitational store of the system man-Earth for all three routes. The teacher summarizes the different point of views and presents the correct answer.

Concluding the lesson, the teacher hand-over responsibility of learning to students by asking them to try out the ideas staged in novel situations included in the relevant worksheet assigned as homework.

Lesson 8

The learning demands addressed in this lesson are:

- understand that when a spring (or any other elastic object) is deformed (stretched or compressed) there is energy in an Elastic store. Furthermore, there is not 'pressure' stored in a deformed spring (or in another elastic object) but rather an amount of energy in the elastic store of the spring.

The teaching goals which address the learning demand are:

To introduce, and support the development of, the ideas that:
- a deformed (stretched or compressed) elastic object has energy in an Elastic store.

To draw attention to, and to emphasize, the ideas that:
- the amount of energy in the elastic store of a deformed spring equals the amount of energy being transferred along a mechanical working pathway done by a force of the form F=k.x (Hooke's law) which acts on the spring and causes the deformation.

To develop the ability to:
- calculate the amount of energy in the elastic store of a deformed spring or other elastic object.

The teacher asks the students to recall the idea of elastic store. Then, the teacher stages the energy knowledge defined by the teaching goals by presenting them with a simulation in which a spring and a ruler in a vertical position are illustrated. The spring compresses by slotted masses which are put on its top end whereas the ruler shows its length for each compression. The teacher provides the information that the natural length of the spring is Lo=30cm, the compression of the spring is caused by slotted masses of 100g each, each slotted mass causes a reduction in the spring's length of 5cm and that the compression of the spring is considered as frictionless. This simulation was designed to focus the students' thinking on: (i) the direct proportionality relation between the force exerted on a spring and the compression or extension caused by the force on the spring, which expresses Hooke's law, (ii) the idea that the amount of energy being transferred along a mechanical working pathway done by a force which is exerted on an elastic object and causes its deformation, equals the amount of energy being stored in the elastic store of the deformed elastic object.

In the next phase, the teacher supports student internalization by drawing a table on the whiteboard and asking the students to fill the possible values of mass m(Kg)/ force F(N)/ length of the spring L(m)/ $x=\Delta L=L-Lo$ (m). Then, she asks to students to draw the graph force against compression $F=f(x)$. At this point, the teacher reviews the students' views and introduces Hooke's law. Then, the teacher initiates the procedure of mathematical verification of the calculating formula of the amount of energy in an elastic store. Again, she supports students' internalization by addressing a sequence of leading questions to the class such as: (i) Can you make the energy description of the event of the simulation?, (ii) Can you draw the Sankey diagram of the system?, (iii) Compare the amount of energy being transferred along a mechanical working pathway and the amount of energy stored in the elastic store of the compressed spring, (iv) The force which causes the deformation of the spring is of variable magnitude. How can mechanical working done by a force of variable magnitude be calculated?, (v) Which law applies for the force which causes the deformation of the spring? Then, the teacher performs the mathematical calculations and verifies the formula.

The teacher hands-over responsibility of learning to students by assigning them the tasks included in the relevant worksheet as homework.

Lesson 9

The learning demand addressed in this lesson is:

- understand that when an object moves vertically, downwards or upwards, there is energy in the gravitational store of the system object-Earth **and** the kinetic store of the object the sum of which is called mechanical store; furthermore, mechanical store is conserved under ideal conditions.

The teaching goals which address the learning demand are:

To introduce, and support the development of, the idea that: • the sum of the Gravitational store of the system object-Earth and the Kinetic store of an object which moves freely in a downward or an upward direction is called Mechanical store. To draw attention to, and to emphasize, the idea that: • the amount of energy in a mechanical store is conserved only under certain conditions; this is known as the conservation of mechanical store theorem.

The teacher administers to the students a 20-minute short-length diagnostic test which aimed to probe the students' understanding on the energy ideas after their qualitative and quantitative treatment.

In order for the teacher to stage for the class the energy knowledge to be addressed in this lesson, she presents a simulation in which the ball-semi-sphere vessel system is illustrated. On the vessel, five consecutive points are marked: A: upper point, B: middle point, C: lowest point, D: middle point, E: upper point. The ball rolls from point A to E and back to point E. Specifically, this simulation was designed to focus the students' thinking on: (i) the idea of mechanical store as the sum of gravitational store of the system object-Earth and the kinetic store of an object which moves freely in a downward or in an upward direction, (ii) the idea of the conservation of mechanical store which is an expression of the fundamental principle of conservation of energy which is valid only under ideal conditions; that is, it is valid for processes in which no degradation of energy takes place.

The teacher supports student internalization by asking them to explain why the ball repeats its motion from one upper end to the other recalling thus the idea of the conservation of energy. Then, she elicits and explores the students' views by asking them to make an energy description of the process which takes place in the system of the simulation as the ball passes through the consecutive points A, B, C, D and E. In the following, the teacher reviews the students' responses and introduces the idea of mechanical store and its calculating formula. Hence, she proceeds to the introduction of the conservation of mechanical store theorem. At this point, the teacher emphasizes that the mechanical store theorem is a conditional expression of the conservation of energy principle.

The teacher hands-over responsibility of learning of the ideas staged to students by asking them to try them out in novel situations included in the relevant worksheet assigned as homework.

Lesson 10

The learning demand addressed in this lesson is:

- understand that when an object moves vertically, downwards or upwards, there is energy in the gravitational store of the system object-Earth **and** the kinetic store of the object the sum of which is called mechanical store; furthermore, mechanical store is conserved under ideal conditions.

The teaching goal which addresses the learning demand is:

To develop the ability to: • apply the conservation of mechanical store theorem to solve qualitative and quantitative energy problems.

This lesson includes the quantitative treatment of the conservation of mechanical store theorem in the analysis of energy problems. The teacher asks the students to present and justify their responses on the tasks included in the relevant worksheet which they had to complete as homework on the whiteboard. In the case of a mistaken or incomplete response, the teacher guides the students to the correct answer.

Post-testing

The teaching intervention is completed with the administration to the students a post-test aimed to collect the students' conceptions on the concept of energy after the teaching intervention.

4.11 AN ACCOUNT OF CONDUCTING THE INSTRUCTIONAL INTERVENTION

As it is discussed in detail in the previous chapter, the teaching intervention for both the experimental and the comparison group was carried out in three stages. In stage one the students participated in the experimental and the comparison group were pre-tested by administering them the same pre-test. In stage two, the instruction of the concept of energy took place. Moreover, further data collection was carried out through the two short-length diagnostic probes and interviewing four students who volunteered to be interviewed. Experimental students were taught through the ten-lesson research-informed teaching sequence presented in Figure 4.11. Comparison students were taught through a six-lesson teaching sequence instead of the eight-lesson 'normal' teaching sequence presented in Figure 4.12; the reasons for the change in the teaching plan are discussed in a following paragraph. Finally, in stage three the students of both groups were post-tested by administering them the same post-test.

In the following, a detailed account of the three stages of the teaching intervention is presented and discussed.

Stage one

During the first stage, the pre-instructional interpretations about energy of the students participated in the experimental and the comparison group were collected through a pre-test. Due to the fact that the physics lessons for the intact classes which acted as the experimental and the comparison group respectively were scheduled in different days within the week in the fixed school timetable, simultaneous pre-testing was not possible. However, the same pre-testing procedure was followed for both groups.

In initiating the pre-testing procedure, the researcher thanked both the teacher and the students for their consent to participating in the research. It has to be noted that eighteen students out of nineteen in the experimental group and eighteen students out of twenty two in the comparison group consented to participate in the research. Then, the researcher clarified that the test would not be used to assess their achievement in physics but strictly to serve the aims of the research and asked the students to work individually and on their best on the tasks comprised in it. Hence, she administered the pre-test (Appendix A) to the students, asked them to study it for a few moments and provided them with some explanation. She explained that the test consisted of two parts: the tasks comprised in part A were referred to the event of the simulation (spring-ball system) which would be presented to them in the following by her whereas in part B they would be presented with tasks related to six simple images provided in the text. In the next, she proceeded to the presentation of the simulation and repeated it for two more times. Then, she asked the students to start working on the pre-test and informed them that the time available for its completion was thirty minutes. At the end of the permitted time, the researcher collected the pre-tests and thanked both the teacher and the students for their cooperation.

Stage two

During the second stage, the experimental intervention and further data collection were conducted. As far as it concerns the intact class acting as the experimental group, the experimental intervention involved a ten-lesson research-informed teaching sequence. Data was collected through the two short-length diagnostic probes, the two interviews with students, interview with the teacher and video recordings of the lessons. For the class acting as the comparison group, they underwent a six-lesson 'normal' teaching sequence. For the comparison class data was collected through video recordings of the lessons.

Regarding the experimental group, the instruction of energy started the very next lesson after pre-testing. At the end of the first lesson, the researcher asked for volunteers for interviewing. She clarified that interviewing would be restricted to physics and no questions on personal affairs would be addressed. Six students, three high, one middle to lower and, two low achievers, volunteered. As it was designed, two of the three high and two low achievers were selected randomly for interviewing. This decision was based on the fact that four students, two low and two high achievers to be interviewed, was considered as a satisfactory number for providing data for answering the third research question.

The first lesson was followed by the second and the third in which the introduction of the energy ideas and the terminology proposed completed. At this point it should be noted that two factors affected rather negatively the effectiveness of the instruction: the first was that due to scheduled school activities, the available time for these lessons ranged between 30-

35 minutes instead of the fixed 45 minutes in the school timetable. However, the teacher manipulated efficiently the available time, followed the lesson plans to her best having in mind their importance, since these consist of the core of the teaching sequence, managing thus to minimize the negative effects on students' learning. The second factor that acted rather negatively on the instruction was the presence of the video camera. A few students showed poorer classroom behavior than was usual, and a few students expressed some objections to its presence, although consented to participate to the research.

As it was designed, in the first fifteen minutes of the fourth lesson the first short-length diagnostic probe was administered to the students by the teacher. Only ten students completed diagnostic probes handed to the researcher since three students were absent to school activities and another five appeared reluctant to take the test. After the collection of the diagnostic probes, the teacher proceeded to the introduction of the idea of mechanical working. At the end of the fourth lesson, the teacher and the researcher had a friendly discussion with the history and the technology teachers of the class in which they were asked to release the four students volunteered for interviewing from their classes the next day. The teachers consented and the researcher conducted the next day the first interview with the students in the school's library.

The experimental intervention was interrupted by Easter holidays for two weeks. Then followed the fifth lesson concerning mechanical working and three lessons concerning kinetic, gravitational and elastic stores respectively. In these lessons, the majority of the students seemed to be more confident and attending with the new approach and relaxed in the presence of the video camera whereas only a few seemed to be still very active and less attending.

Again as it was designed, in the first twenty minutes of the ninth lesson the second short-length diagnostic probe was administered to the students by the teacher. All fifteen present students responded and the completed diagnostic probes handed to the researcher by the teacher. After the collection of the diagnostic probes, the teacher continued with the introduction of the idea of mechanical store and the conservation of mechanical store theorem.

The instruction of energy in the experimental group finished with the tenth lesson of the research-informed teaching sequence. At the end of the lesson, the teacher and the researcher had another friendly discussion with the religion studies teacher of the class in which she was asked to release the two low achievement students from her class the next day in order to be interviewed. The teacher consent and the researcher conducted the second interview with the two low achievement students. The two high achievement students were also interviewed at the same day after they were released from the physics class.

After the completion of the experimental intervention, the researcher had a meeting with the experimental teacher. In this meeting, the researcher conducted a long interview with the teacher in which a wide range of issues concerning the content of the lessons, the means used, the available time for the introduction of each energy idea and the structure of the teaching sequence were discussed in detail. Furthermore, the teacher was keen to comment also on the students' attitudes towards the new approach and its impact on their learning and to express her personal views about the new approach as being the experimental teacher providing with thus much valuable feedback about its effectiveness and suggestions for its improvement.

Turning to the intact class acted as the comparison group, the instruction of energy started a few lessons after pre-testing and with delay as to the date agreed between the researcher and the comparison teacher. In a meeting after pre-testing, the teacher informed the researcher about the delay and that due to school time limitations, he would restrict the instruction of energy in a six-lesson teaching sequence instead of an eight-lesson one as defined in the current curriculum. Furthermore, he informed the researcher about his decision to restrict the teaching of mechanical work in one half instead of two lessons by reducing the number of worked examples and not proceeding to the experimental verification of Hooke's law by the students which normally takes place in the time of a normal lesson. Rather, he would introduce Hooke's law prior to the introduction of the idea of elastic potential energy. Furthermore, he would omit the introduction of the mechanical work-kinetic energy theorem which usually takes the time of half lesson. In the light of these arrangements decided by the teacher, a new starting date was agreed so as post-testing for both the experimental and the comparison group take place in the same week.

However, the teacher initiated the instruction of energy a lesson earlier than that at the agreed starting date and for that reason, the researcher missed the opportunity to video record the first lesson in which the idea of work was introduced. In the second lesson, exercises on work assigned as homework from the book were checked and the idea of kinetic energy was introduced. In presenting a worked example, the conservation and degradation aspects of energy were briefly discussed after a relevant question posed to the teacher by a student.

In the third lesson, homework on kinetic energy assigned from the book was checked and then the introduction of the idea of gravitational energy and discussion of a worked example took place. The third lesson was followed by fourth in which checking of homework on gravitational energy assigned from the book preceded. Hence, Hooke's law was presented followed by the introduction of the idea of elastic potential energy. No exercises were assigned on Hooke's law but only on elastic energy as homework. In the fifth lesson, homework was checked and the idea of mechanical energy and the conservation of mechanical energy were introduced. Then, the teacher proceeded to the presentation of a worked example in which the aspects of conservation and degradation of energy were discussed. At the end of the lesson, a worksheet was administered by the teacher to the students and assigned as homework. The sixth and last lesson of the teaching sequence included checking and discussion on the tasks comprised in the worksheet.

Stage three

During the third stage, the interpretations about energy of the students participating in the experimental and the comparison group after the experimental intervention were collected through a post-test. For the same reasons as in the case of pre-testing, post-testing of the students in the two groups took place in different days but within the same week. Also, the same post-testing procedure was followed for the two groups.

At the start of the post-testing procedure, the researcher informed the students that a post-test would be administered to them, clarified that this would not be used for any other purpose than to serve the aims of the research and asked them to work individually and on their best on the tasks comprised in it. Then, she administered the post-test (Appendix B) to the students and asked them to study it for a few moments. She briefly explained to them that the post-test consisted of two parts: part A was the same as the corresponding in pre-test and part B which comprised tasks referred to the systems illustrated in the two images. In the following, she presented the simulation (spring-ball system) once, asked the students to start working on the test and informed them that the available time for its completion was forty minutes. At the end of the permitted time, she collected the post-tests and thanked the teacher and the students for their contribution in the research.

CHAPTER 5: EVALUATION OF THE TEACHING: FINDINGS FOR RQ1 AND RQ2

In Chapter 3, the design of the research carried out in this doctoral thesis was presented and discussed in detail. Emphasis was placed on the decisions made concerning the appropriate kinds and the design of the research instruments to be used for the evaluation of the research-informed teaching sequence for energy proposed in Chapter 4.

This chapter focuses on the evaluation of the teaching through the research-informed sequence. In particular, findings revealed from analysis of the data collected through pre and post-test are presented and discussed. Based upon them, answers to RQ1 and RQ2 are formulated. The two research questions addressed in Chapter 3 are as follows:

RQ1. What concepts of energy are used by a Cypriot cohort of upper high school students prior to teaching?

RQ2. How do the conceptions and learning of the sub-cohort of Cypriot students taught through the research-informed approach compare with those following 'normal teaching' after instruction?

Evaluation of the innovative teaching concludes in the next chapter in which the findings revealed from the case studies are presented and through them, an answer to RQ3 is formulated.

5.0 INTRODUCTION

This chapter presents a detailed account of the analysis carried out for data collected from experimental and comparison group students at pre and post instructional stage. In the first section, findings of the pre-test data analysis are presented and discussed. The first research question and the ways in which the findings revealed from pre-test data analysis were used for the formulation of an answer to the first research question are restated, as these were formulated in Chapter 3-Research Methodology.

Regarding the pre-test data analysis carried out, coding categories for both the experimental and the comparison group students' pre-instructional responses were derived in order their views before teaching of the concept of energy be compared with those reported in the international science education literature. This allowed for an answer to the first research question. The rationale of how coding categories were derived from this kind of data collected is described and discussed in detail in section 3.4.1.

In addition, a statistical study was conducted looking for significant differences between the pre-instructional responses of students in the experimental and the comparison group aiming to establish that students in each group were comparable concerning their initial energy knowledge prior to instruction. This is required for the second research question; however, it is reported in the first section of the chapter as it was considered as more efficient to be included in that rather in the second section.

In the second section, findings revealed from post-test data analysis are presented and discussed. The second research question and the ways in which these findings were used to formulate an answer to this question are also stated once again. In particular, the second research question is addressed by comparing the experimental and the comparison students' responses after the instruction of the concept of energy. Furthermore, a statistical study was conducted looking for significant differences between the post-instructional responses of students in the experimental and the comparison group aiming to illuminate the findings of the comparison described previously.

This is followed by a third section in which a comparison of the results revealed from experimental group post-test's part A and part B data respectively across the contexts is performed. This kind of analysis aimed to examine the students' ability in transferring the acquired energy knowledge from familiar to novel situations and thus to examine the extent to which experimental students had what might described as a 'stable' or 'consistent' model of energy. Findings were used as further evidence to address the second research question.

The chapter concludes with a fourth section in which, the key findings of the previous three sections are summarized and discussed and answers to RQ1 and RQ2 are formulated.

5.1 PRE-INSTRUCTIONAL STAGE

The results of analysis of the responses of the eighteen students participating in the experimental group and the eighteen students participating in the comparison group to the pre-test questions are presented in comparative tables for each individual question and in bar charts. The various qualitative different categories of response in these tables were identified by applying the coding scheme described in Appendixes G and H respectively. In addition, data from pre-test part A was exposed to statistical analysis using the Fisher's Exact Test.

Results presented both in the tables and the bar charts are discussed. The discussion aimed to findings which allowed the formulation of an answer to the first research question:

RQ1.What concepts of energy are used by a Cypriot cohort of upper high school students prior to teaching?

As stated in Chapter 3, the answer to this question aimed to serve two key purposes: first, to check whether the initial interpretations of the Cypriot students on energy coincide with some of those reported in the international science education literature; if yes, to identify these specific interpretations and; whether there are any other initial interpretations not yet identified. Information on these issues were considered in the design and the development of the innovative instructional approach, presented and discussed in detail in Chapter 4, to increase its effectiveness in promoting conceptual understanding of the concept of energy. Second, to determine the initial conditions of the study, that is, whether or not the sub-cohort of students which was taught through the research-informed approach was initially equivalent in terms of energy knowledge to that receiving the 'normal teaching'. Information on the initial equivalency of the two sub-cohorts was used to establish the validity of the findings of the study as required by Research Methods Literature. Specifically, this was used in the comparative study of the effectiveness of teaching in the two sub-cohorts and to the formulation of an answer to RQ2. Furthermore, information on the students' initial interpretations about energy was used for the development of the energy learning profile of a small-group of experimental students and to formulate an answer to RQ3.

In the following, the pre-test part A results are presented and discussed followed by those of pre-test part B.

PART A

5.1.1 Students' initial performance in formulating a physical description of a process which takes place in a physical system.

Question 1: Describe carefully and in detail what you see happening in the simulation- no explanation needed!

Four coding categories were identified which are shown in Table 5.1.

Table 5.1: Categories of initial responses describing physically the event of the simulation.

Category number	Category description	Experimental group	Comparison group	Total
		Freq.	Freq.	Freq.
1	**The spring expands and sets the ball in motion in which it decelerates and finally stops.** *'At first the ball is at rest and when the spring is released the ball initially moves along with the end of the spring. As soon as the spring opens the ball leaves its end and starts to decelerate until it stops.'*	6/18	6/18	12/36
2	**The spring expands and sets the ball in a decelerated motion.** *'There is a spring which pushes hard a ball and in the end it* (the ball) *reduces speed.'*	3/18	12/18	15/36
3	**The spring expands and sets the ball in motion.** *'We observed a spring which is compressed and a ball in front of it. In the following the spring stretches and pushes the ball and because of this the ball moves away from it.'*	6/18	0/18	6/36
4	**The spring expands and pushes the ball.** *'The spring opens and pushes the ball.'*	3/18	0/18	3/36

The coding categories shown in Table 5.1 were further examined with respect to whether they include a full, a partially full or an incomplete physical description. The results revealed on the grounds of this kind of classification are shown in Table 5.2.

Table 5. 2: Students' initial performance in formulating a physical description of the event of this simulation.

Category number	Category description	Experimental group		Comparison group		Total	
		Freq.	Freq. perc.%	Freq.	Freq. perc. %	Freq.	Freq. perc.%
1	**Full physical description.**	6/18	33	6/18	33	12/36	33
2	**Partially full physical description.**	9/18	50	12/18	67	21/36	58
3	**Incomplete physical description.**	3/18	17	0/18	0	3/36	9

Results shown in Table 5.2 concerning the total number of participant students are presented in the bar chart of Figure 5.1.

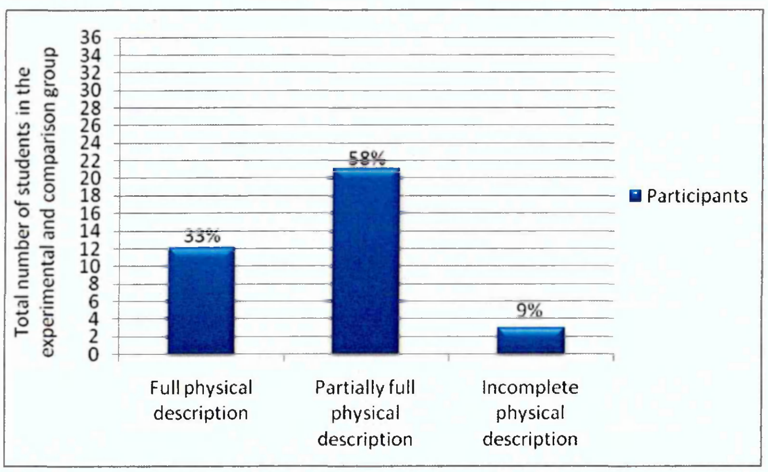


Figure 5.1: Total number of students who formulated a full, a partially full or an incomplete physical description.

More than half of the students formulated a partially full physical description, neglecting the event of the ball coming to rest. One way of interpreting this result is that the students possibly consider as physical events only those in which a kind of activity, movement or interaction between objects takes place. Thus, the event of the ball coming to rest is considered either as a non physical event or as an event of no importance to be mentioned.

Furthermore, the results shown in Table 5.2 for each individual group are also presented in comparison in the bar chart of Figure 5.2.

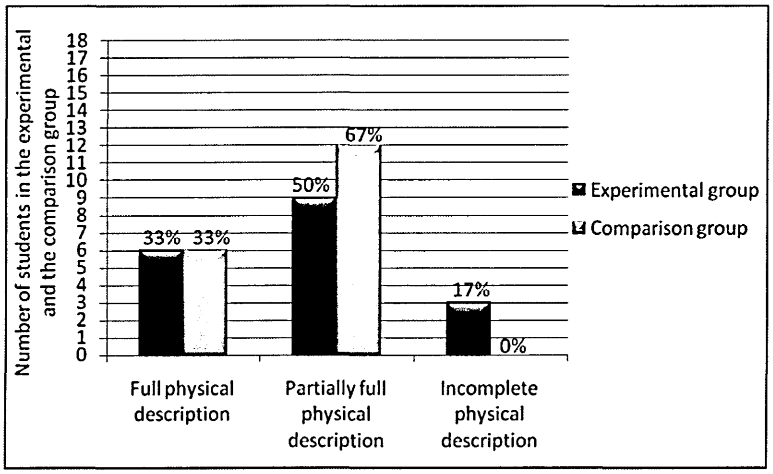


Figure 5.2: Number of students who formulated a full, a partially full or an incomplete physical description.

The diagram suggests a slightly higher overall ability in describing physically a process among students in comparison group compared to that of students in experimental group. Nevertheless, the number of students who formulated a full physical description is the same for both groups.

Overall, results presented above suggest that the majority of the participant students formulated a partially full physical description of the event of the simulation prior to experimental intervention. Furthermore, the number of students who formulated a full physical description is exactly the same for both the experimental and comparison group.

5.1.2 Students' initial views in interpreting the changes observed in a physical system.

Question 2a: For each of the events in the simulation described above: explain as best as you can why they occurred.

Eight coding categories were identified which are shown in Table 5.3.

Table 5.3: Categories of initial responses interpreting the event of the simulation.

Category number	Category description	Experimental group	Comparison group	Total
		Freq.	Freq.	Freq.
	Events happen because of energy.			

1	*'They happen because there is energy.'*	0/18	4/18	4/36
2	**The spring gives kinetic energy to the ball which starts to move. The ball is decelerated due to friction and finally stops.** *'The end of the spring gives kinetic energy to the ball. The ball starts to move and because of friction it stops after a while. Springs have a property ...'.*	1/18	0/18	1/36
3	**The spring exerts a force on the ball as it expands which causes the ball's movement. The ball finally stops because no force is exerted on it.** *'The ball moves along with the end of the spring because the spring is released suddenly and the ball goes with the end of the spring in order to retain its initial speed. After the spring opened the ball decelerated because there is no force to be exerted on it.'*	1/18	0/18	1/36
4	**The spring exerts a force on the ball as it expands which causes the ball's movement.** *'Initially the spring did not exert a force on the ball and for that reason the ball was at rest. Hence the spring opened and exerted a force on the ball and because of this the ball moved. Because the spring exerted a force on it* (on the ball)*.'*	11/18	11/18	22/36
5	**The spring exerts a force on the ball as it expands which causes the ball's movement. The ball decelerates and finally stops because of friction.** *When the spring is released it exerts a force on the ball which starts to move but it decelerates because of friction and stops.'*	0/18	2/18	2/36
6	**The compressed spring gives the force which has in it to the ball as it expands and the ball starts to move. The ball stops because of friction.** *'The compressed spring retains some force and with the abrupt release of this force the small ball receives a certain* (quantity of) *force. The small ball stops because of friction.'*	1/18	1/18	2/36
7	**The compressed spring pushes the ball as it expands and gives impulse to the ball. The ball is decelerated because impulse is reduced.** *'The spring is compressed because we press it. When it is released it pushes the ball and gives its impulse but as time passes this*	1/18	0/18	1/36

	impulse is reduced.'			
8	**No response.**	3/18	0/18	3/36

As seen from the table, the students interpreted the observed changes through referencing energy, force and impulse. Thus, coding categories shown in Table 5.3 could be further classified on the grounds of the variation of the concepts the students accounted for in their interpretations. The results of this kind of classification are shown in Table 5.4.

Table 5.4: Students' initial performance in formulating an energy description of the event of the simulation.

Category number	Category description	Experimental group		Comparison group		Total	
		Freq.	Freq. perc. %	Freq.	Freq. perc. %	Freq.	Freq. perc. %
1	**Interpretation based on energy.**	1/18	6	4/18	22	5/36	14
2	**Interpretation based on other concept:** **-Force** **-Impulse**	13/18 1/18	72 6	14/18	78	28/36	78
3	**Interpretation none.**	3/18	16	0/18	0	3/36	8

Results shown in the above table for the total number of participant students are presented in the bar chart of Figure 5.3.

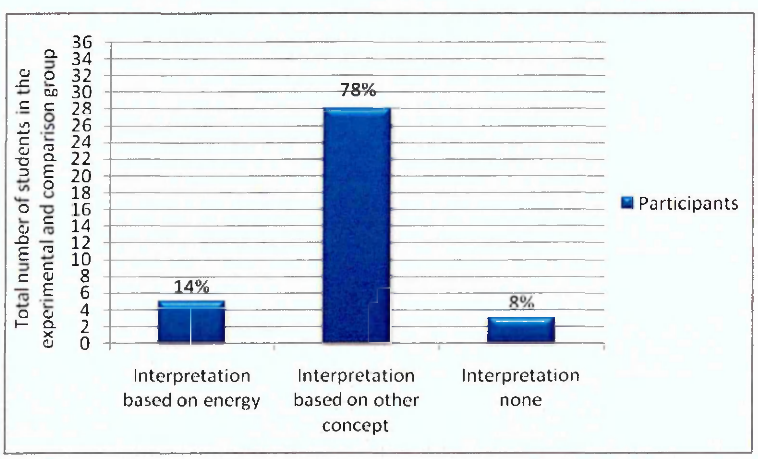


Figure 5.3: Total number of students who formulated an energy-based or a non energy- based interpretation for the event of the simulation.

The above bar chart clearly shows that only a very small number of the participant students interpreted the observed changes in the system of the simulation through referencing energy; the great majority formulated a force based interpretation. Moreover, results shown in Table 5.4 for each individual group are presented in the comparative bar chart of Figure 5.4.

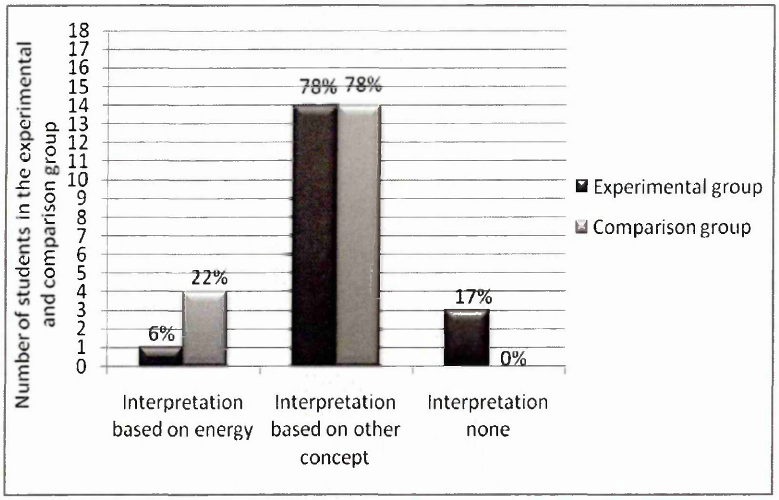


Figure 5.4: Number of students who formulated an energy-based or a non energy- based interpretation for the event of the simulation.

As can be seen a slightly bigger number of comparison students (4) use the energy concept as compared with experimental students (1). Furthermore, results of the statistical analysis concerning the number of students who use the energy concept in the two groups are shown in Table 5.5.

Table 5.5: Results of Fisher's Exact Test about the number of students in the two groups who initially used energy in their interpretations

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	2.090[a]	1	.148		
Continuity Correction[b]	.929	1	.335		
Likelihood Ratio	2.218	1	.136		
Fisher's Exact Test				.338	.169
N of Valid Cases	36				

a. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 2.50.

b. Computed only for a 2x2 table

In the above table, the *p* value for Fisher's Exact Test is $p=0.338>p_{cutedge}=0.05$. Thus, there is no significant difference in the number of students who used energy in their interpretations in the two groups.

Overall, as the results presented above suggest, only a very small number of the participant students interpreted the event of the simulation through referencing energy whereas the great majority used force.

5.1.3 Students' initial views about energy at the beginning of a physical process.

Question 2b: At the very BEGINNING of the simulation event, is there any energy? YES or NO? If YES, where? If NO, why not?

Seven coding categories were identified which are shown in Table 5.6.

Table 5.6: Categories of initial responses about energy at the beginning of the event of the simulation.

Category number	Category description	Experimental group	Comparison group	Total
		Freq.	Freq.	Freq.
1	**Yes. There is energy in the compressed spring.** *'Yes. In the compressed spring.'*	5/18	6/18	11/36
2	**Yes. There is energy in the spring produced by a force.** *'Yes. There was in the spring which was compressed that is a force was exerted on it and energy was produced.'*	0/18	3/18	3/36
3	**Yes. There is energy in the spring when it pushes the ball.** *'Yes. At the beginning there was energy in the spring when it pushed the ball.'*	2/18	3/18	5/36
4	**Yes. There is energy in the ball/ the spring and the ball.** *'Yes. In the ball.'*	0/18	3/18	3/36
5	**Yes. There is energy.** *'YES.'*	2/18	0/18	2/36
	No. There isn't energy because the objects			

6	**were at rest.** *'NO. No because both objects were at rest.'*	7/18	3/18	10/36
7	**No. There isn't energy because no force is exerted on the objects.** *'NO. Because no force is exerted on the objects.'*	2/18	0/18	2/36

In order to identify the number of students who stated that there is energy in the system at the beginning of the event, coding categories shown in Table 5.6 were classified. The results of this kind of classification are shown in Table 5.7.

Table 5.7: Students' initial views about energy at the beginning of the event of the simulation.

Category number	Category description	Experimental group		Comparison group		Total	
		Freq.	Freq. perc. %	Freq.	Freq. perc. %	Freq.	Freq. perc. %
1	**There is energy at the beginning.**	9/18	50	15/18	83	24/36	67
2	**There isn't energy at the beginning.**	9/18	50	3/18	17	12/36	33

Results shown in Table 5.7 concerning the total number of participant students are presented in the bar chart of Figure 5.5.

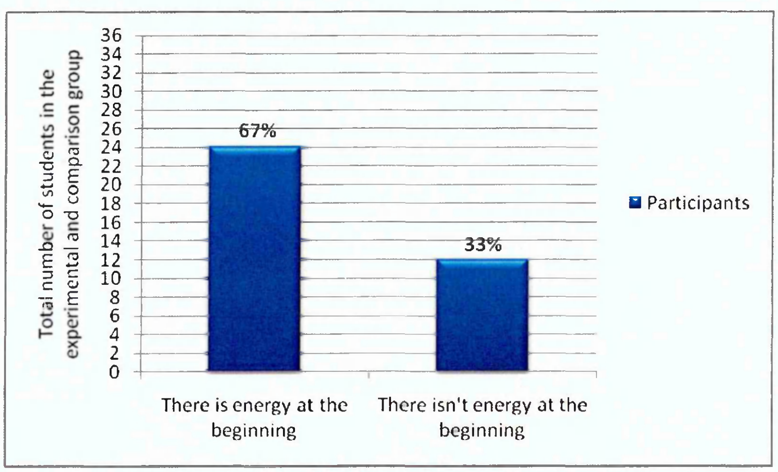


Figure 5.5: Total number of students who stated that there is or there isn't energy in the system at the beginning of the event of the simulation.

The majority of students stated that there is energy at the beginning of the event.

Results shown in Table 5.7 concerning the two individual groups are compared in the bar chart of Figure 5.6.

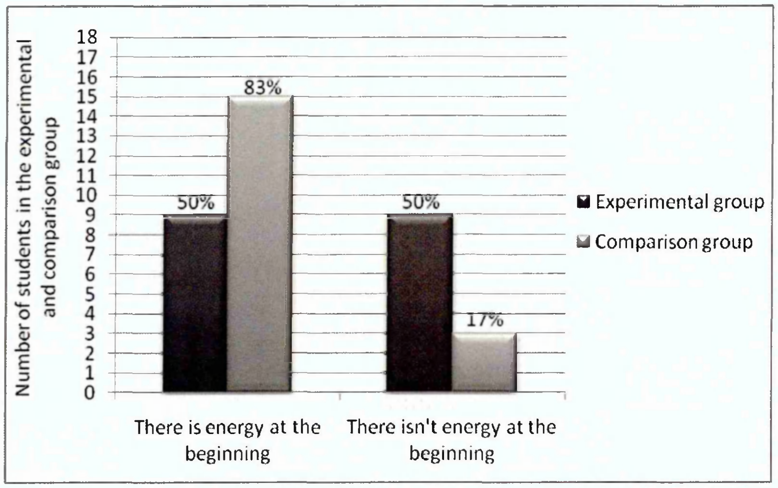


Figure 5.6: Number of students who stated that there is or there isn't energy in the system at the beginning of the event of the simulation.

A greater number of students in the comparison group (15) stated that there is energy at the beginning of the event compared to the corresponding number of those in the experimental group (9).

At this point, it is worth making a further examination of the coding categories in which the nine students in the experimental group and the fifteen students in the comparison group stated that there is energy at the beginning of the event, with respect to as to whether they were justified through correct or incorrect reasoning respectively. Thus, the results of this kind of classification are shown in Table 5.8.

Table 5.8: Categories of initial responses stating and justifying correctly/incorrectly that there is energy at the beginning.

Category number	Category description	Experimental group		Comparison group		Total	
		Freq.	Freq. perc. %	Freq.	Freq. perc. %	Freq.	Freq. perc. %
1	**There is energy at the beginning- Correct reasoning.**	5/18	28	6/18	33	11/36	31
2	**There is energy at the beginning-No reasoning.**	2/18	11	0/18	0	2/36	6

3	**There is energy at the beginning-Incorrect reasoning.**	2/18	11	9/18	50	11/36	31

Results shown in Table 5.8 for the total number of participant students are shown in the bar chart of Figure 5.7.

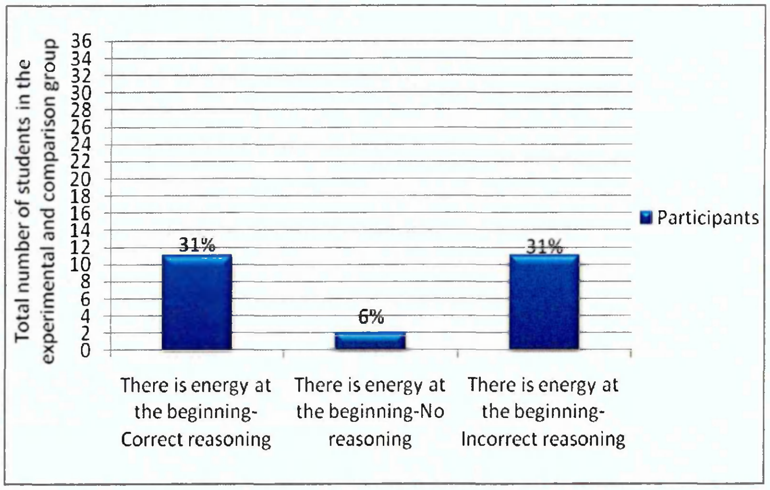


Figure 5.7: Total number of students who stated that there is energy in the system at the beginning of the event and justified correctly their statement.

Thus, among the twenty four students who stated that there is energy at the beginning, only eleven justified their response through a correct reasoning. In examining the other thirteen students' responses classified in coding categories 2-5 in Table 5.6 it seems that they justified their response through referencing force or objects which are involved in an activity.

Moreover, the results shown in Table 5.6 for the two groups are compared in the bar chart of Figure 5.8.

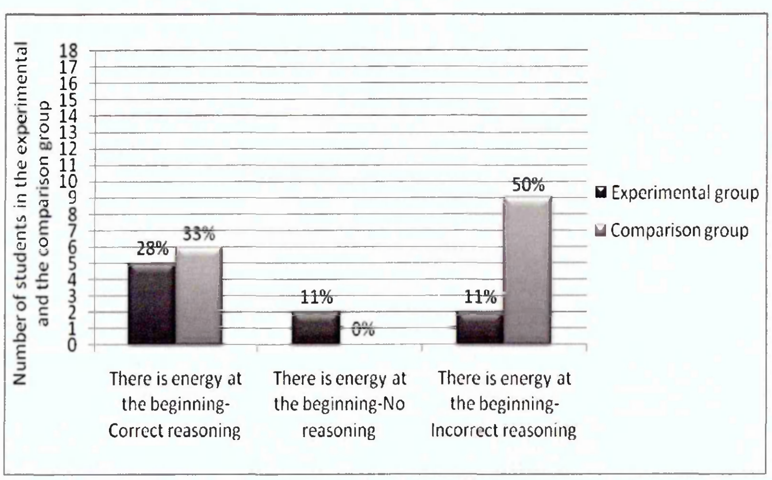


Figure 5.8: Number of students who stated that there is energy in the system at the beginning of the event and justified correctly their statement .

As remarked earlier, a greater number of students in the comparison group stated that there is energy in the system at the beginning compared to the corresponding number in the experimental group. Nevertheless, the chart of Figure 5.8 clearly suggests that there is no actual difference in the number of students in both groups who stated that there is energy at the beginning and justified their statement through a correct reasoning. In particular, the difference is focused on the number of students who stated that there is energy at the beginning who justified their statement through incorrect reasoning. An example of correct response justified through an incorrect reasoning is the following: *'Yes. At the beginning there was energy in the spring when it pushed the ball.'*

Moreover, results of statistical test of the number of students who stated that there is energy at the beginning and justified correctly in the two groups are shown in Table 5.9.

Table 5.9: Results of Fisher's Exact Test about the number of students in the two groups who stated and justified correctly that there is energy at the beginning

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.131[a]	1	.717		
Continuity Correction[b]	.000	1	1.000		
Likelihood Ratio	.131	1	.717		
Fisher's Exact Test				1.000	.500
N of Valid Cases	36				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 5.50.

b. Computed only for a 2x2 table

The *p* value for Fisher's Exact Test is $p=1.000>p_{cutedge}=0.05$. Thus, there is no difference in the number of students who stated that there is energy at the beginning and justified correctly their statement between the two groups.

Overall, according to the results presented above, there was some form of understanding of the store aspect of energy among the participant students prior to teaching intervention. Furthermore, there is no actual difference in the number of students in the experimental and the comparison group who stated and justified correctly that there is an energy store at the beginning of the event.

5.1.4 Students' initial views about energy at the end of a physical process.

Question 3: Think now about the END of the simulation event, when the ball has stopped moving. Is there any energy? YES or NO? If YES, explain. If NO, why not?

Eight coding categories were identified which are shown in Table 5.10.

Table 5.10: Categories of initial responses about energy at the end of the event of the simulation.

Category number	Category description	Experimental group	Comparison group	Total
		Freq.	Freq.	Freq.
1	**Yes. There is energy and it is transformed to heat.** *'YES. Heat energy because of friction between the ball and the ground.'*	1/18	0/18	1/36
2	**Yes there is. Energy continues to exist and is transformed from one form to another.** *'The ball had kinetic energy and once it stopped this energy was converted to another kind. Energy never disappears. It is always converted from one kind to another.'*	0/18	2/18	2/36
3	**Yes. There is 'static' energy.** *'Yes. Because there is static energy.'*	2/18	0/18	2/36
4	**No. There isn't any energy because it was released when the spring expanded.** *'NO. No because energy was released during the expansion.'*	0/18	1/18	1/36
5	**No. There isn't any energy because the ball/the objects come to rest.** *'NO. Because if there was any energy then the ball would keep moving.'* and *'NO. Because the ball stopped at a point and the spring decompressed completely.'*	10/18	11/18	21/36
	No. There isn't any energy because no force is exerted.			

6	*'NO.* *There isn't any force.'*	1/18	4/18	5/36
7	**No. There isn't any energy because the force of the ball run out because of friction.** *'NO.* *Because the ball used the force which the spring gave it to friction.*	1/18	0/18	1/36
8	**No.** *'NO.'*	3/18	0/18	3/36

In order to identify the number of students who stated that there is energy at the end of the event, coding categories shown in Table 5.10 were classified as shown in Table 5.11.

Table 5.11: Students' initial views about energy at the end of the event of the simulation.

Category number	Category description	Experimental group		Comparison group		Total	
		Freq.	Freq. perc. %	Freq.	Freq. perc. %	Freq.	Freq. perc. %
1	**There is energy at the end.**	3/18	17	2/18	11	5/36	14
2	**There isn't energy at the end.**	15/18	83	16/18	89	31/36	86

Results shown in Table 5.11for the number of participant students is shown in the bar chart of Figure 5.9.

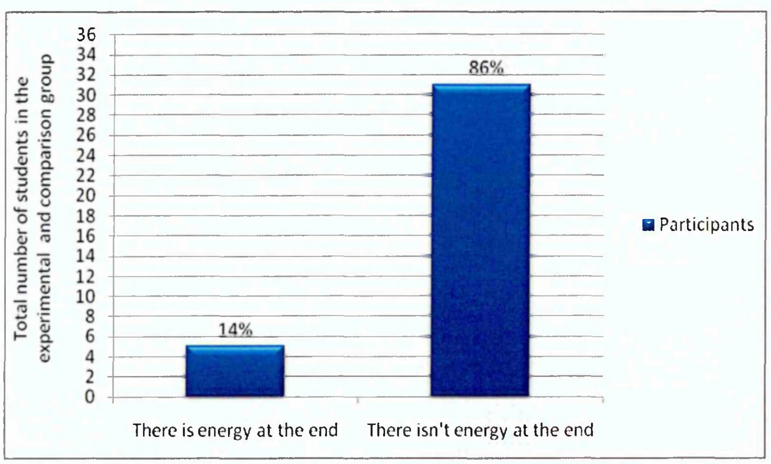


Figure 5.9: Total number of students who stated that there is or there isn't energy at the end of the event of the simulation.

In the following, results shown in Table 5.11 concerning each individual group are compared in the bar chart of Figure 5.10.

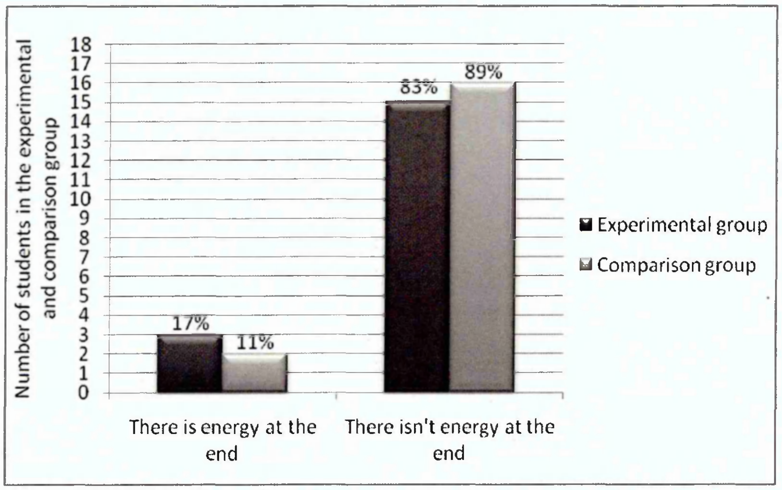


Figure 5.10: Number of students who stated that there is or there isn't energy in the system at the end of the event of the simulation.

Thus, there is no actual difference in the number of students who stated that there is energy at the end of the event in the experimental and the comparison group. Furthermore it should be remarked that this number is small for both groups.

At this point, it might be worth a further classification of the coding categories in which the three students in the experimental group and the two students in the comparison group who stated that there is energy at the end of the event as to whether they justified through correct or incorrect reasoning respectively. Thus, the results of this kind of classification are shown in Table 5.12.

Table 5.12: Categories of initial responses stating and justifying correctly/incorrectly that there is energy at the end.

Category number	Category description	Experimental group		Comparison group		Total	
		Freq.	Freq. perc. %	Freq.	Freq. perc. %	Freq.	Freq. perc. %
1	**There is energy at the end- Correct reasoning.**	1/18	6	2/18	11	3/36	8
2	**There is energy at the end-Incorrect reasoning.**	2/18	11	0/18	0	2/36	6

Results shown in Table 5.12 for the total number of participant students are presented in the bar chart of Figure 5.11.

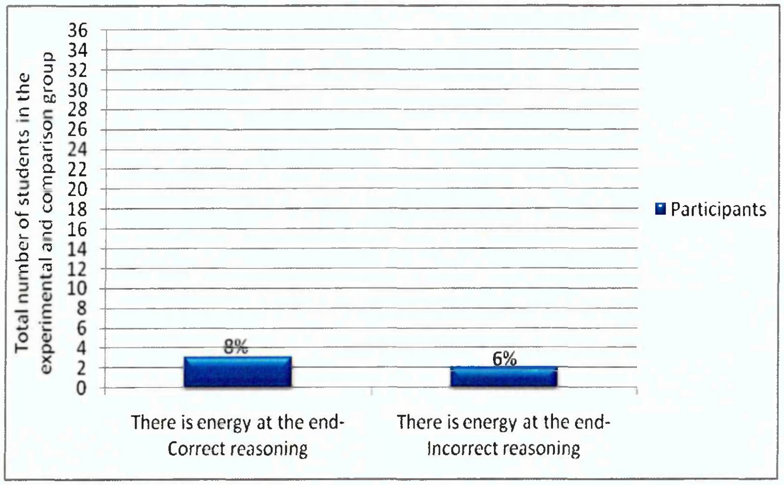


Figure 5.11: Total number of students who stated that there is energy at the end of the event and justified correctly their statement.

The above bar chart clearly shows that only a very small number of three out of the thirty six participant students stated that there is energy at the end of the event and justified correctly their statement. Furthermore, it might be of interest to focus on the three students' responses classified in categories 1 and 2 in Table 5.10. Their correct responses were justified through the idea of energy transformation, which is consistent within the 'forms' of energy framework.

Furthermore, the results in Table 5.12 for the two individual groups are presented in comparison in the bar chart of Figure 5.12.

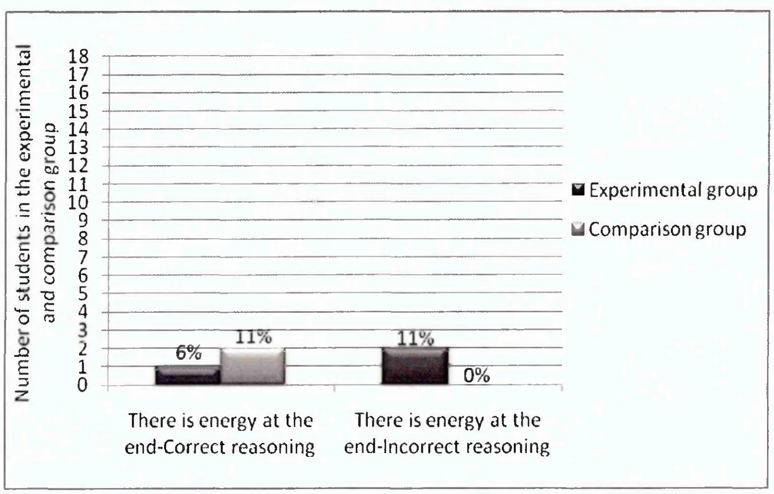


Figure 5.12: Number of students who stated that there is energy at the end of the event and justified correctly their statement.

Thus, the number of students who stated that there is energy at the end of the event and justified correctly their statement is small for both the experimental and the comparison group. Also, it seems that there isn't a real difference between these numbers for the two groups.

Results of statistical test of the number of students who stated that there is energy at the end and justified correctly their statement in the two groups are shown in Table 5.13.

Table 5.13: Results of Fisher's Exact Test about the number of students in the two groups who initially stated and justified correctly/incorrectly that there is energy at the end.

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.364[a]	1	.546		
Continuity Correction[b]	.000	1	1.000		
Likelihood Ratio	.370	1	.543		
Fisher's Exact Test				1.000	.500
N of Valid Cases	36				

a. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 1.50.

b. Computed only for a 2x2 table

The p value for Fisher's Exact Test is $p=1.000>p_{cutedge}=0.05$. Thus, there is no difference in the number of students who stated that there is energy at the end and justified correctly their statement in the two groups.

Overall, the results presented above suggest that there was very limited understanding of the transfer aspect of energy among the participant students prior to teaching intervention. The very small number of students who stated that there is energy at the end and justified correctly their statement used the ideas of energy transformation and conservation in their reasoning.

5.1.5 Students' initial views about the amount of energy at the beginning and the end of a physical process.

Question 4: What can you say about the amount of energy at the BEGINNING compared with the amount of energy at the END?

Five coding categories were identified which are shown in Table 5.14.

Table 5.14: Categories of initial responses about energy at the beginning and the end of the event of the simulation.				
Category number	**Category description**	**Experimental group**	**Comparison group**	**Total**
		Freq.	**Freq.**	**Freq.**
1	**The amount of energy at the beginning is the same with the amount of energy at the end.** *'Energy was the same at the beginning and at the end.'*	1/18	2/18	3/36
2	**The amount of energy at the beginning is greater than the amount of energy at the end.** *'There is more at the beginning.*	5/18	4/18	9/36
3	**There is energy at the beginning but not at the end.** *'At the beginning there was energy whereas at the end energy disappeared.'*	1/18	9/18	10/36
4	**There isn't any energy at the beginning or at the end.** *'At the beginning the amount of energy is zero as it is and at the end because they do not move at all. '*	6/18	3/18	9/36
5	**No response.**	5/18	0/18	5/36

In order to identify the number of students who stated that the amount of energy at the beginning is the same as the amount of energy at the end, coding categories shown in Table 5.14 are classified accordingly. The results of the classification are shown in Table 5.15.

Table 5.15: Students' initial views about energy conservation.							
Category number	**Category description**	**Experimental group**		**Comparison group**		**Total**	
		Freq.	**Freq. perc. %**	**Freq.**	**Freq. perc. %**	**Freq.**	**Freq. perc. %**
1	**Energy is conserved.**	1/18	6	2/18	11	3/36	8

2	**Energy is not conserved.**	12/18	66	16/18	89	28/36	78
3	**No response.**	5/18	28	0/18	0	5/36	14

Results shown in Table 5.15 for the total number of students are shown in the bar chart of Figure 5.13.

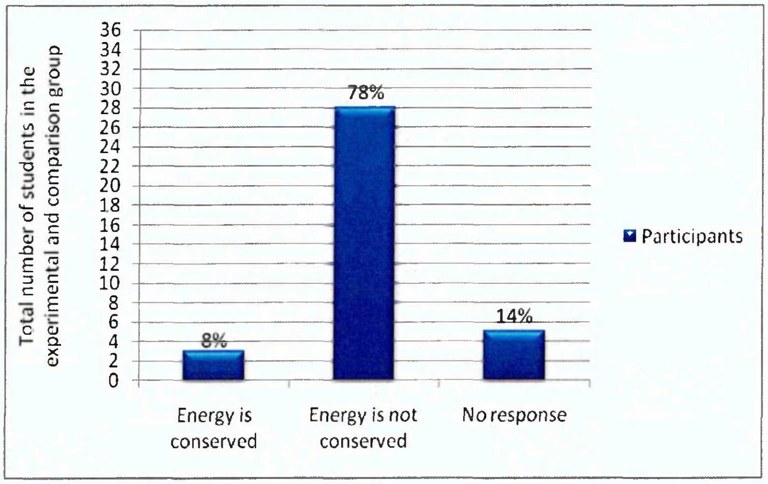


Figure 5.13: Number of students who stated that energy is/is not conserved.

Thus, the great majority of the students stated that the amount of energy at the beginning is not the same as that at the end. These results suggest a very limited understanding of the conservation of energy aspect among the participant students prior to teaching intervention.

Results shown in Table 5.15 for the two individual groups are presented in comparison in the bar chart of Figure 5.14.

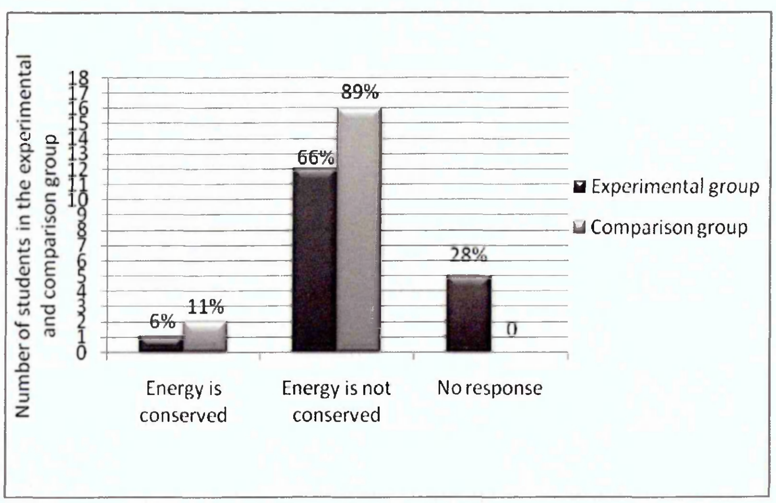


Figure 5.14: Number of students who stated that energy is/is not conserved.

The above chart shows about the same negligible number of students in the experimental and comparison groups who stated that the amount of energy at the start is the same with that at the end. Furthermore, results of statistical test are shown in Table 5.16.

Table 5.16: Results of Fisher's Exact Test about the number of students in the two groups who stated initially that energy is conserved.

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.364[a]	1	.546		
Continuity Correction[b]	.000	1	1.000		
Likelihood Ratio	.370	1	.543		
Fisher's Exact Test				1.000	.500
N of Valid Cases	36				

a. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 1.50.

b. Computed only for a 2x2 table

The above table shows p value for Fisher's Exact Test equal to $p=1.000>p=0.05$. Thus, there is no difference in the number of students who stated that the energy of the system is conserved between the two groups.

Overall, the results presented above suggest that there wasn't an understanding of the conservation of energy aspect among the participant students prior to teaching intervention since only one student in the experimental group and two in the comparison group stated that energy is conserved.

5.1.6 Students' initial performance in formulating an energy description of a physical process which takes place in a physical system.

Question 5: Finally, describe overall what has happened to the energy of the event from BEGINNING to END.

Five coding categories were identified which are shown in Table 5.17.

Table 5.17: Categories of initial responses formulating a scientifically or an alternative oriented energy description.

Category number	Category description	Experimental group	Comparison group	Total
		Freq.	Freq.	Freq.
	Scientifically oriented energy description.			
1	**- The 'Forms' of energy conceptual framework.** - At the beginning, energy was in the spring and it was given to the ball as kinetic. Then, once the ball stopped, it was converted to heat energy. *'At the beginning energy was in the spring. That gave it to the ball (kinetic) and hence because of friction it was converted to heat energy, whereas the ball stopped moving.'*	1/18	0/18	1/36
2	**- The 'Conservation' of energy conceptual framework.** - Energy remained the same during the event. *'Energy did not change during the event.'*	0/18	2/18	2/36
	'Alternative' oriented energy description.			
3	**- The 'energy consume' conceptual model.** - At the beginning, energy was in the spring and then it was given to the ball to move. Once the energy consumed, the ball stopped moving. *'At the beginning there was much accumulated energy in the spring which was released to the ball which started to move until the energy consumed and the ball stopped.'*	6/18	8/18	14/36
4	**- The 'product' conceptual model.** - At the beginning, there wasn't any energy. Once the ball started to move, there was energy. At the end, when the ball stopped moving, there wasn't any energy. *'At the beginning there wasn't any energy, but when the ball started to move forward there was energy. At the end when it reached* (the ball) *its destination there wasn't energy anymore.'*	3/18	2/18	5/36
5	**No response.**	8/18	6/18	14/36

Results shown in the above table, concerning the total number of participant students are presented in the bar chart of Figure 5.15.

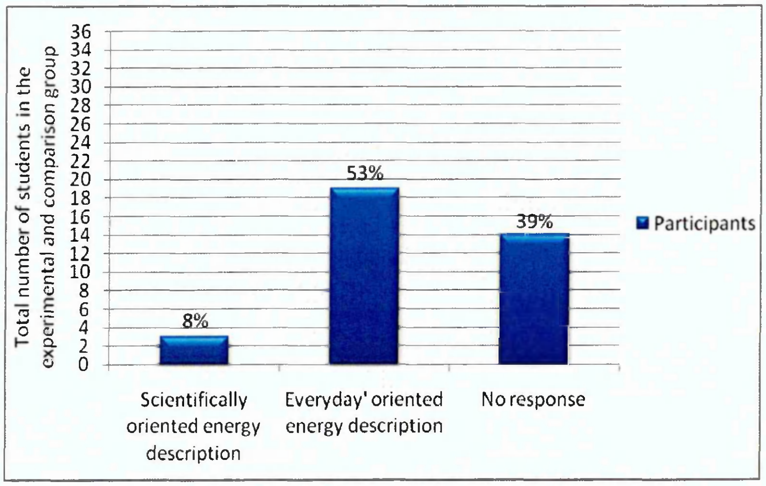


Figure 5.15: Total number of students who formulated a scientific or an 'alternative' oriented energy description.

Thus, only a very small number of students formulated a scientifically oriented energy description whereas the majority offered an 'alternative' oriented one. Furthermore, a large number of students did not succeed in formulating any energy description.

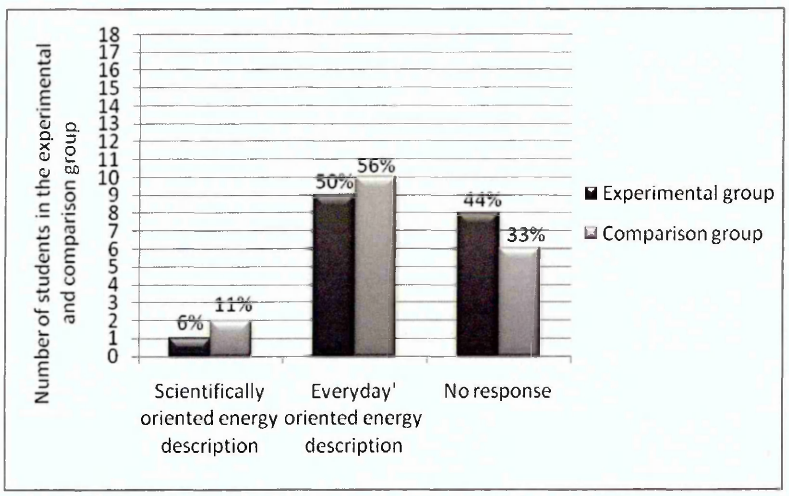


Figure 5.16: Number of students who formulated a scientific or an 'alternative' oriented energy description.

The bar chart shows that there isn't any real difference in the number of students in the experimental and comparison group who formulated a scientifically oriented energy description prior to teaching intervention. Moreover, this number is negligible for both groups.

In the following, coding categories shown in Table 5.17 are further examined on the grounds of the students' understanding of the degradation of energy aspect. The results of this kind of classification are shown in Table 5.18.

Table 5.18: Students' initial views about energy degradation.

Category number	Category description	Experimental group		Comparison group		Total	
		Freq.	Freq. perc. %	Freq.	Freq. perc. %	Freq.	Freq. perc. %
1	**At the end, energy was transformed to heat.**	1/18	6	0/18	0	1/36	3
2	**At the end, energy remained the same/consumed.**	9/18	50	12/18	67	21/36	58
3	**No response.**	8/18	44	6/18	33	14/36	39

Results in Table 5.18 concerning the total number of participant students are presented in the bar chart of Figure 5.17.

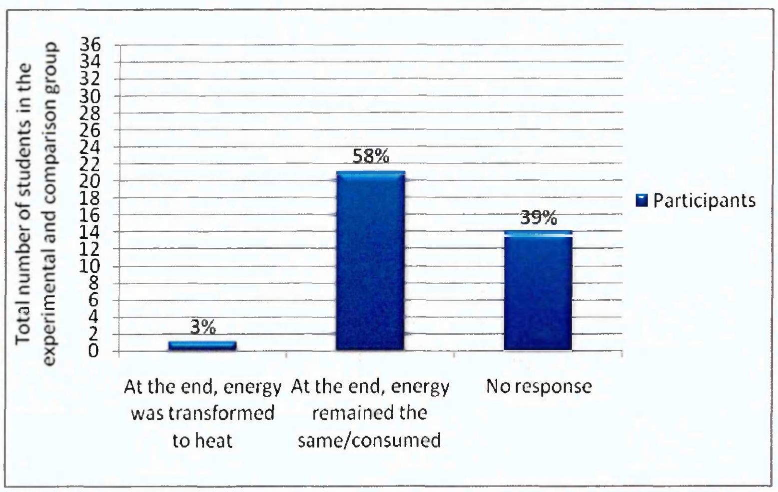


Figure 5.17: Total number of students who stated that energy is/is not degraded.

Thus, only one out of the thirty six students had expressed some ideas on the degradation aspect of energy. These results suggest that there wasn't any understanding of the degradation of energy aspect prior to teaching intervention among the participant students.

Furthermore, the results shown in Table 5.18 for the two individual groups are presented in the comparative bar chart of Figure 5.18.

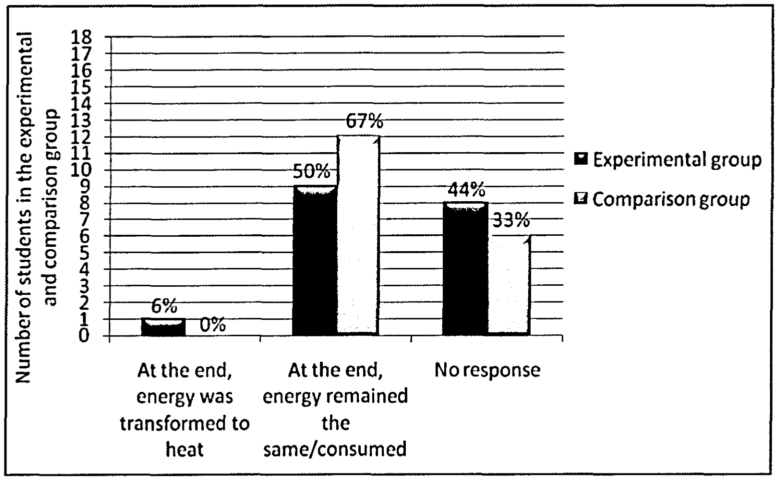


Figure 5.18: Number of students who stated that energy is/is not degraded.

The diagram shows that there is no real difference in the number of students in the experimental and the comparison group who expressed ideas on degradation. In addition, results of statistical test are shown in Table 5.19.

Table 5.19: Results of Fisher's Exact Test about the number of students in the two groups who stated initially that energy is degraded.

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	1.029[a]	1	.310		
Continuity Correction[b]	.000	1	1.000		
Likelihood Ratio	1.415	1	.234		
Fisher's Exact Test				1.000	.500
N of Valid Cases	36				

a. 2 cells (50.0%) have expected count less than 5. The minimum expected count is .50.

b. Computed only for a 2x2 table

The p value for Fisher's Exact Test is $p=1.000>p=0.05$. Therefore, there is no difference in the number of students who stated that the energy of the system is degraded between the two groups.

Overall, as the results presented above suggest, the majority of the students held ideas on energy within an 'alternative' framework whereas a large number did not formulate any energy description. Regarding the two individual groups, the number of students in the experimental group who used some ideas within a scientific framework in their energy descriptions has no real difference from the corresponding number in the comparison group. Furthermore, there wasn't any understanding of the degradation aspect of energy among the participant students but one student in the experimental group who expressed some degradation ideas.

PART B

5.1.7 Students' initial views about the energy concept.

Question : Look at the following. Which of them has energy? Give a brief explanation.

The coding categories identified from students' responses on each of the six images included in the above question were further categorized across more general alternative energy models and are shown in Tables 5.20 - 5.25.

Sub-question 1:

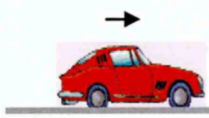

A moving car

Table 5.20: Categories of responses about the energy of a moving car.

Category number	Category description	Experimental group	Comparison group	Total
		Freq.	**Freq.**	**Freq.**
1	**Correct energy model.** - There is kinetic and heat energy. *'Yes. KINETIC HEAT'*	1/18	0/18	1/36
	'Activity' model of energy.			
2	- There is energy because the car moves. *'YES. Because it moves. Motion is energy.'*	13/18	12/18	28/36
3	- There is energy because the engine provides force/a force is exerted on the car. *'YES. The motor (engine) provides the force.'*	2/18	1/18	
	'Functional' model of energy.			

4	- There is energy because the car consumes some to move. *'YES. The car moves and consumes energy.'*	0/18	5/18	5/36
5	**No implicit model.** - There is energy. *'YES.'*	1/18	0/18	1/18
6	**No response.**	1/18	0/18	1/36

Results shown in Table 5.20 concerning the total number of participant students are presented in the bar chart of Figure 5.19.

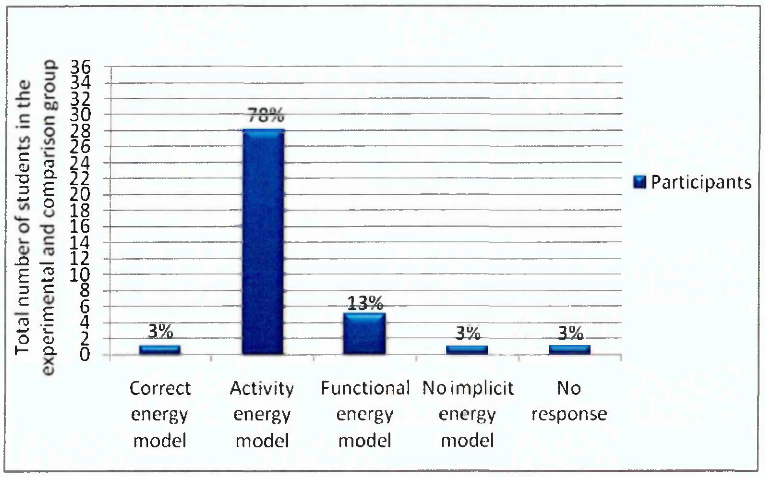


Figure 5.19: Total number of students who expressed ideas about the energy of the system within the correct/activity/functional model.

The great majority of the participant students expressed ideas about the energy of the system within the 'activity' model whereas a smaller number used the 'functional' model. Some of the characteristic 'activity' ideas, which were more extensively discussed in Chapter 2, identified in the participant students' responses are that energy is strongly associated with motion and in addition, that motion itself is considered as energy. Furthermore, another characteristic notion identified is that there is energy because a force is exerted.

Regarding the 'functional' model, one of the characteristic notions identified in the participant students' responses is that energy is considered as a general kind of fuel which is needed in order an engine or a device to function.

The results shown for the two individual groups are as follows.

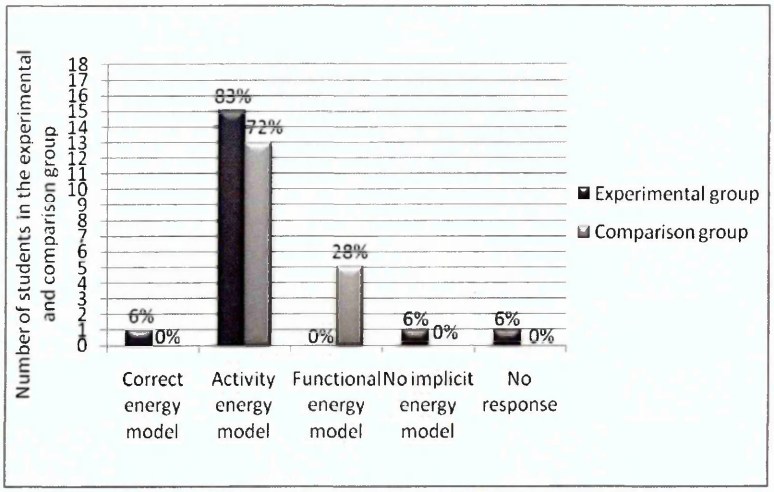


Figure 5.20: Number of students who expressed ideas about the energy of the system within the correct/activity/functional model.

The bar chart shows that there isn't much difference in the number of students who expressed ideas within the 'activity' model in the experimental and the comparison group respectively. The students who expressed ideas within the 'functional' model all participated in the comparison group.

Sub-question 2:

A battery

Table 5.21: Categories of responses about the energy of a battery.				
Category number	**Category description**	**Experimental group**	**Comparison group**	**Total**
		Freq.	**Freq.**	**Freq.**
1	**'Depository' model of energy.** - There is energy because the battery is an energy source/stores energy. *'YES. A battery is an energy source for some objects.'* and *'Yes. There is energy in it.'*	6/18	3/18	
2	- There is energy because there is electricity/electric voltage in the battery. *'YES. There is energy because there is electricity in it*	1/18	1/18	

3	(in the battery).' - There isn't any energy because the battery does not function/is not connected to a device. *'NO.* *It is not in function.'* and *'It is not connected somewhere so as to be in function.'*	7/18	8/18	26/36
4	**'Activity' model of energy.** -There isn't any energy because the battery is at rest.	0/18	2/18	2/36
5	**No implicit energy model.** - There is energy. *'YES.'*	1/18	1/18	7/36
6	- There isn't any energy. *'NO.'*	2/18	3/18	
7	**No response.**	1/18	0/18	1/36

Results shown in Table 5.21 are also shown in the bar chart of Figure 5.21.

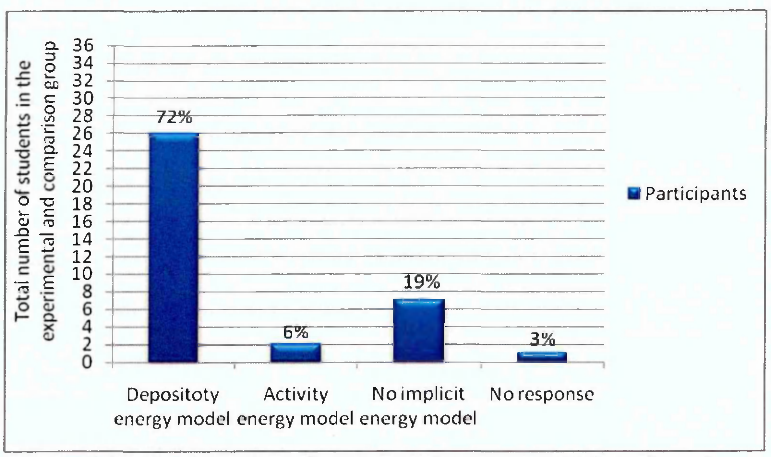


Figure 5.21: Total number of students who expressed ideas about the energy of the system within the depository/activity model.

The great majority of the participant students expressed ideas within the 'depository' model whereas a very small number ideas within the 'activity' model. As it was discussed in Chapter 2, one of the characteristic 'depository' ideas identified in the participant students' responses is that some devices such as batteries store energy, need energy or consume the energy which they posses; in other words, energy is considered as a causal agent which is stored in specific objects or devices such as batteries. Another characteristic 'depository' notion identified is that energy is associated with the function of a certain device which in this case is battery. Furthermore, a third characteristic notion identified among the participant students is that certain devices such as batteries and their function are associated with energy income coming from electricity. In addition, concerning the 'activity' model, the energy of the system of the battery is solely associated with the battery's state of movement.

Results shown for the two individual groups are as follows.

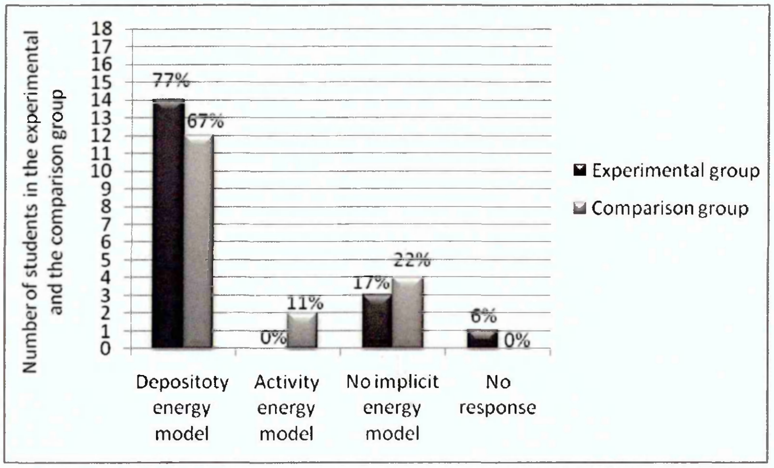


Figure 5.22: Number of students who expressed ideas about the energy of the system within the depository/activity model.

As the bar chart shows, there is only a small difference in the number of students in the experimental and comparison group who expressed ideas within the 'depository' model. The very small number of students who expressed ideas within the 'activity' model participated in comparison group.

Sub-question 3:


A runner

Table 5.22: Categories of responses about the energy of a runner.				
Category number	**Category description**	**Experimental group**	**Comparison group**	**Total**
		Freq.	**Freq.**	**Freq.**

1	**Correct energy model.** - There is kinetic energy. *'YES. KINETIC.'*	1/18	1/18	2/18
2	**'Anthropocentric' model of energy.** - There is energy because the athlete runs/moves. *'Yes. Because he moves then it has energy.'*	14/18	10/18	32/36
3	- There is energy because the runner needs/ produces/consumes energy to move. *'Yes. A runner needs energy to run.'* and *'Yes. The runner runs and so it consumes energy.'*	1/18	7/18	
4	**No implicit energy model.** - There is energy. *'YES.'*	1/18	0/18	1/36
5	**No response.**	1/18	0/18	1/36

Results shown in Table 5.22 are also shown in the following bar chart.

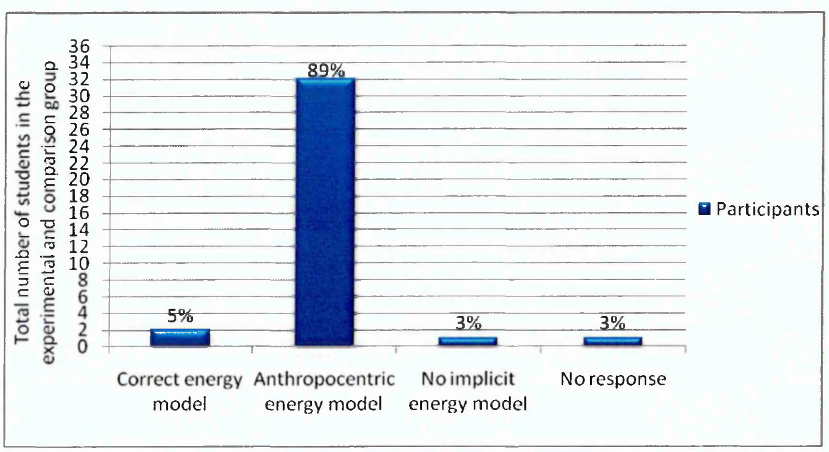


Figure 5.23: Total number of students who expressed ideas about the energy of the system within the correct/anthropocentric model.

Thus, participant students expressed ideas about the energy of the system almost all within the 'anthropocentric' model whereas a negligible number responded correctly that there is kinetic energy. One of the characteristic 'anthropocentric' ideas identified in the participant students' responses, already presented in Chapter 2, is that energy is associated with human's physical activities such as running. Furthermore, another notion identified is that energy is indispensable in order for human beings to move, which is expressed through the ideas that the runner needs/consumes/produces energy when he runs.

The results for the two individual groups are presented below.

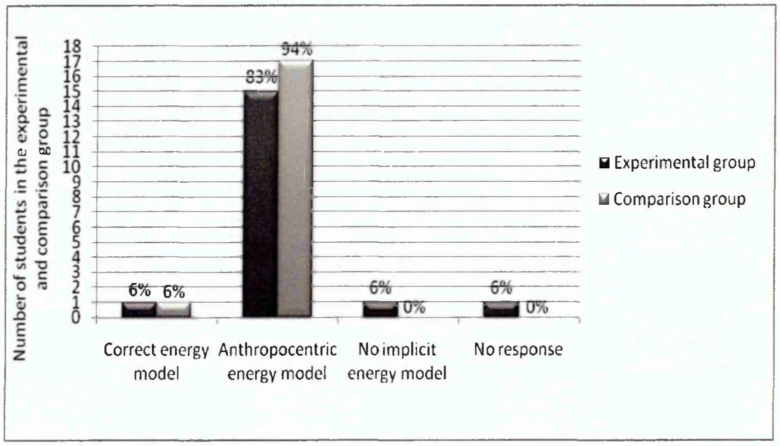


Figure 5.24: Number of students who expressed ideas about the energy of the system within the correct/anthropocentric model.

Thus, the number of students in the experimental and comparison group who expressed 'anthropocentric' ideas is about the same. In addition, the number of students who responded correctly is negligible and exactly the same for the two groups.

Sub-question 4:

A book on a shelf

Table 5.23: Categories of responses about the energy of a book on a shelf				
Category number	**Category description**	**Experimental group**	**Comparison group**	**Total**
		Freq.	**Freq.**	**Freq.**
1	**'Activity' model of energy.** - There isn't any energy because the book is at rest. *'NO.*	15/18	15/18	30/36

	The book is not moving and for that reason there is no energy.'			
2	**No implicit energy model.** - There isn't any energy. *'NO.'*	2/18	3/18	5/36
3	**No response.**	1/18	0/18	1/36

Results shown in Table 5.23 are also shown in the bar chart of Figure 5.25.

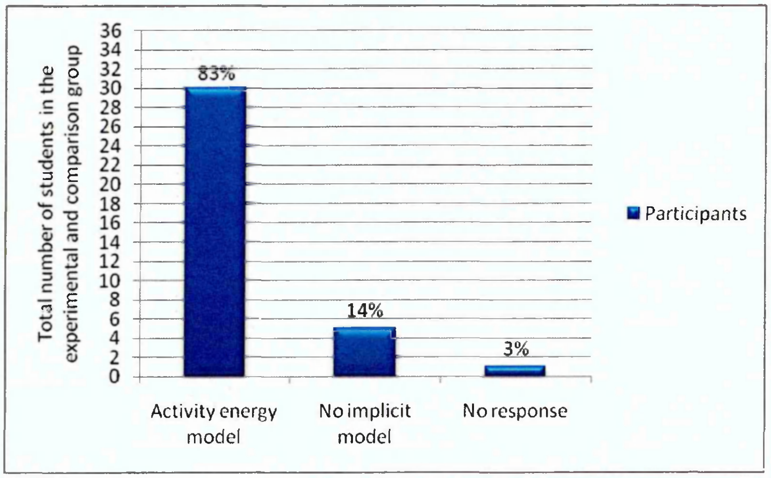


Figure 5.25: Total number of students who expressed ideas about the energy of the system within the activity model.

The bar chart shows that the great majority of the participant students expressed ideas about the energy of the system within the 'activity' model. The characteristic 'activity' idea identified in the students' responses is that energy is strongly associated with the fact that the book does not take part into a kind of motion or activity.

Results for the experimental and comparison group are presented in comparison as follows.

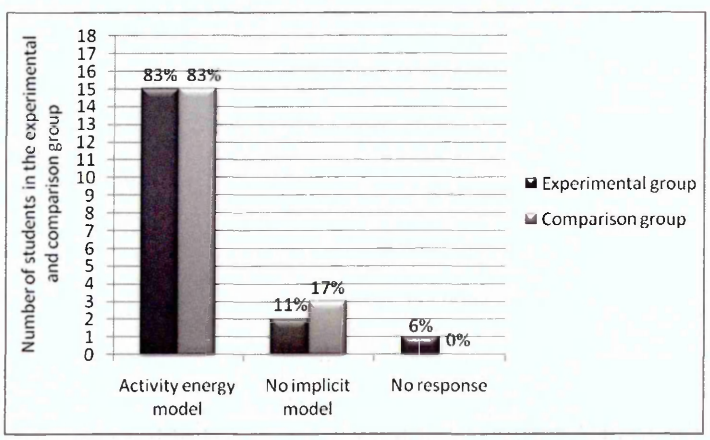
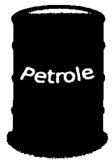


Figure 5.26: Number of students who expressed ideas about the energy of the system within the activity model.

As the bar chart shows, the number of students who expressed ideas within the 'activity' model is exactly the same for both the experimental and comparison group.

Sub-question 5:



A barrel of petrol

Table 5.24: Categories of responses about the energy of a barrel of petrol.

Category number	Category description	Experimental group	Comparison group	Total
		Freq.	**Freq.**	**Freq.**
	'Depository' model of energy.			10/36
1	- There is chemical energy in the petrol. *'YES. There is chemical energy.'* and *'YES. Petrol contains energy which we use in many vehicles.'*	4/18	1/18	
2	-There isn't any energy because the petrol is not used. *'NO. Because it is just a barrel of petrol it is not in a car to give energy.'*	1/18	4/18	
	'Activity' model of energy.			
3	- There isn't any energy because the barrel is at rest. *'NO. The barrel is at rest and for that reason there is no energy.'*	9/18	8/18	17/36
	No implicit energy model.			8/36
4	- There is energy. *'YES.'*	0/18	1/18	
5	- There isn't any energy. *'NO.'*	3/18	4/18	

6	**No response.**	1/18	0/18	1/36

It is interesting that seventeen out of thirty six students used an 'activity' model of energy in justifying their response. This indicates the deep seated nature of students' thinking in relation to energy.

Results shown in Table 5.24 are also shown in the bar chart of Figure 5.27.

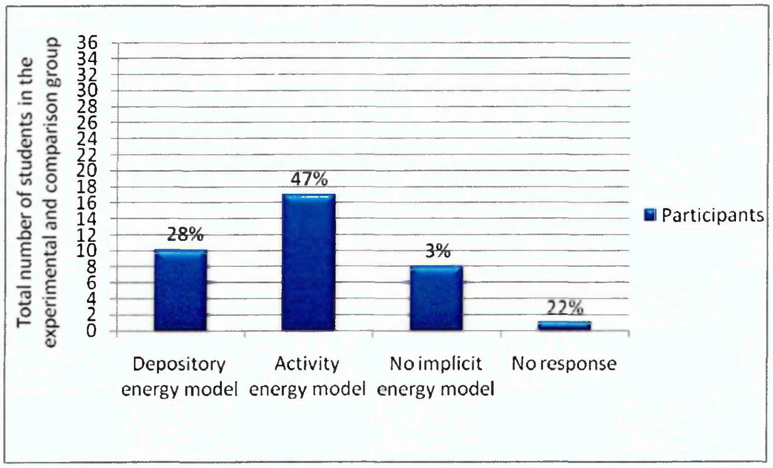


Figure 5.27: Total number of students who expressed ideas about the energy of the system within the depository/activity model.

The bar chart shows that the majority of the participant students expressed ideas about the energy of the system within the 'activity' model whereas a smaller number ideas within the 'depository' model.

Results for the two individual groups are presented below.

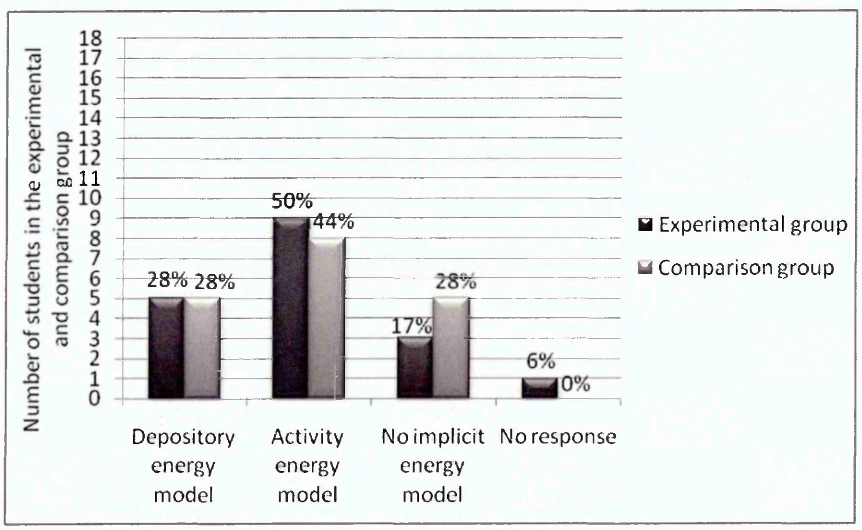
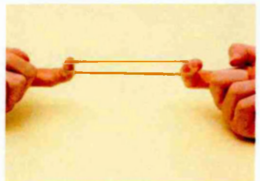


Figure 5.28: Number of students who expressed ideas about the energy of the system within the depository/activity model.

The number of students in the experimental and comparison group who expressed ideas within the 'depository' model is exactly the same whereas there is no actual difference in the number of students who expressed ideas within the 'activity' model in the two groups.

Sub-question 6:



A stretched elastic band.

Table 5.25: Categories of responses about the energy of a stretched elastic band.

Category number	Category description	Experimental group	Comparison group	Total
		Freq.	Freq.	Freq.
1	**Correct energy model.** - There is energy because the band is stretched. *'YES. Because it is stretched from both sides.'*	6/18	7/18	13/36
2	**'Activity' model of energy.** - There is energy because the band needs energy to be stretched. *'Yes. It needs energy to be stretched.'*	4/18	0/18	17/36
3	- There is energy because a force is exerted on the band. *'YES. Because the hands exert a force on the band.'*	4/18	7/18	
4	- There isn't any energy because the band is at rest. *'NO. No because it remains stretched at rest.'*	2/18	0/18	
5	**No implicit energy model.** - There is energy. *'YES.'*	1/18	2/18	5/36

6	- There isn't any energy. *'NO.'*	0/18	2/18	
7	**No response.**	1/18	0/18	1/36

Results shown in Table 5.25 are also shown in the bar chart of Figure 5.29.

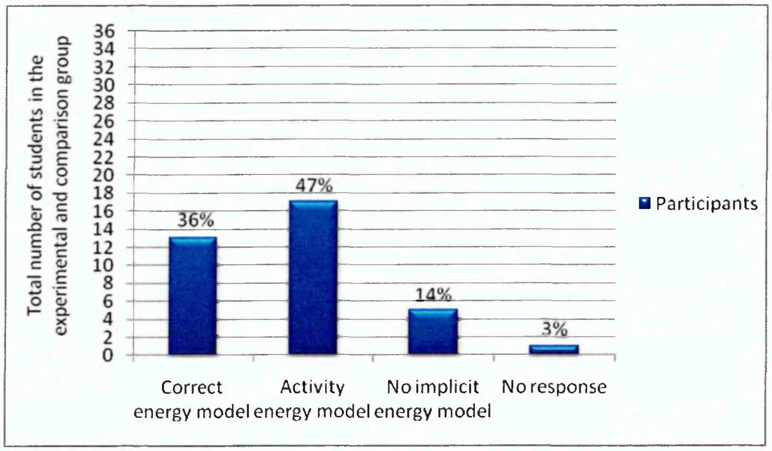


Figure 5.29: Total number of students who expressed ideas about the energy of the system within the correct/activity model.

Thus, the majority of the participant students expressed some 'activity' ideas about the energy of the system whereas a considerable number responded correctly that there is energy because the band is stretched.

Results concerning the two individual groups are presented as follows.

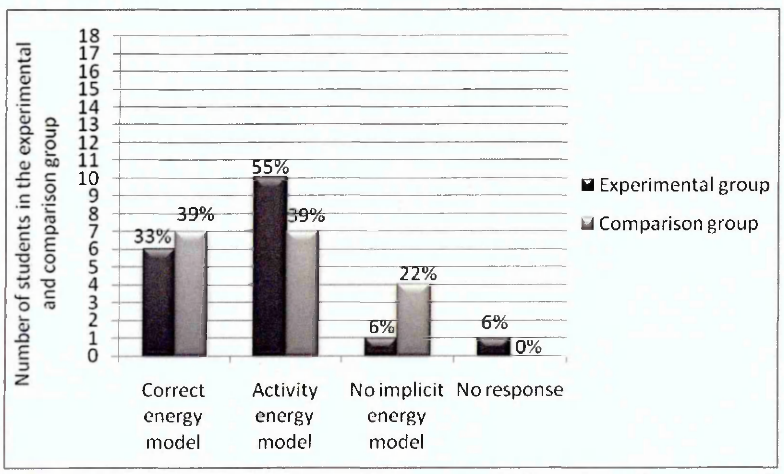


Figure 5.30: Number of students who expressed ideas about the energy of the system within the correct/activity model.

As the bar chart shows, there isn't any actual difference in the number of students in the experimental and comparison group who responded correctly whereas a greater number of students in the experimental group expressed ideas within the 'activity' model.

5.1.8 ESTABLISHMENT OF THE EQUIVALENCY OF THE EXPERIMENTAL AND THE COMPARISON GROUP AT PRE-INSTRUCTIONAL STAGE

Focusing on the findings of both the comparative percentage representation and the statistical study with the use of the Fisher's Exact Test of the experimental and the comparison group results, these clearly suggest no difference between the two groups: (i) in the number of students who formulated an energy-based interpretation of the event of the simulation and, (ii) in the students' understanding on each of the four aspects of the energy concept. Furthermore, findings suggest that students in both the experimental and the comparison group expressed initial ideas on energy which are classified in the same alternative energy models which appear in about the same frequency among students in the two groups.

The findings summarized above clearly suggest that the experimental and the comparison students' responses to the questions at pre-instructional stage were comparable. Therefore, this establishes the validity of comparison of the experimental and the comparison students' post-instructional responses in order the second research question be addressed.

5.2 POST-INSTRUCTIONAL STAGE

In this section, the findings of analysis of the responses of the eighteen students participated in the experimental group and the eighteen students who participated in the comparison group to the post-test questions are presented, as those of pre-test, in comparative tables for each individual question and in bar charts. The various qualitative different categories of response in these tables were identified by applying the coding scheme described in Appendixes I, J and K respectively. Furthermore, data of post-test's part A were exposed to statistical analysis using the Fisher's Exact Test and results are also presented in tables.

Discussion conducted concerning both the findings presented in the tables and the bar charts is focused on those which could provide with an answer to the second research question:

RQ2. How do the conceptions and learning of the sub-cohort of Cypriot students taught through the research-informed approach compare with those following 'normal teaching' after instruction?

The answer to this question aimed to reveal whether the proposed research-informed teaching sequence is effective in promoting conceptual understanding of the concept of energy in comparison to current curriculum for energy and the usually used authoritative approach. Furthermore, if effective, to gain insights on the degree of its effectiveness compared to that of 'normal teaching'.

In the following, the post-test's part A results are presented, then those of part B followed by the experimental group part A and B comparison results.

PART A

5.2.1 Students' performance in formulating a physical description of a process which takes place in a physical system after instruction.

Question 1: Describe carefully and in detail what you see happening in the simulation-no explanation needed!

Three coding categories were identified which are shown in Table 5.26.

Table 5.26: Categories of responses describing physically the event of the simulation after instruction.

Category number	Category description	Experimental group	Comparison group
		Freq.	Freq.
1	**The spring expands and sets the ball in motion which it finally stops.** *'In the simulation we watched a spring which is compressed and a ball in front of it. In the following the spring expands and pushes the ball with a force F and the ball starts to move in a straight line until it stops.'*	11/18	6/18
2	**The spring expands and sets the ball in motion.** *'Initially the spring is compressed and the ball is not moving. Then once we set free the spring the ball starts moving.'*	5/18	10/18
3	**The spring expands and pushes the ball.** *'Initially the ball was closed to the spring and in the following once the spring is set free, it pushes the*	2/18	2/18

	ball.'		

The coding categories shown in Table 5.26 were further examined with respect to whether they include a full, a partially full or an incomplete physical description. The results revealed on the grounds of this kind of classification are shown in Table 5.27.

Table 5.27: Students' performance in formulating a physical description of the event of the simulation after instruction.

Category number	Category description	Experimental group		Comparison group	
		Freq.	Freq. perc. %	Freq.	Freq. perc. %
1	**Full physical description.**	11/18	61	6/18	33
2	**Partially full physical description.**	5/18	28	10/18	57
3	**Incomplete physical description.**	2/18	11	2/18	11

Results shown in Table 5.27 are also shown in the bar chart of Figure 5.31.

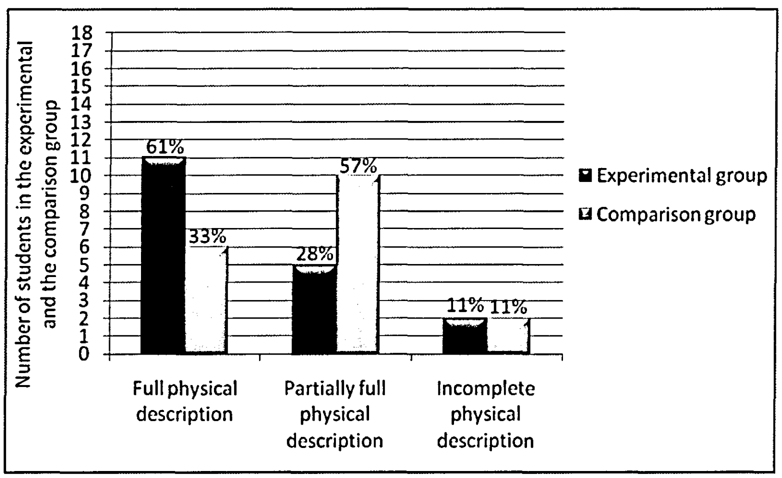


Figure 5.31: Number of students who formulated a full, a partially full or an incomplete physical description.

The diagram suggests a much higher performance in fully describing physically a process among students in the experimental group compared to that of students in the comparison group. Furthermore, it might be of interest the above results be compared with the corresponding of pre-instructional stage shown in Figure 5.1. As it is seen, the number of students who formulated a full physical description was the same in both groups at pre-instructional stage (6); at post-instructional stage, this number almost doubled for students in the experimental group (11) whereas for students in comparison group this number remained the same (6).

Overall, the above results suggest a much higher performance in describing physically the event of the simulation among students in the experimental group compared to that of students in the comparison group at post-instructional stage. Furthermore, this performance seems to be also much higher compared to that of the experimental group students at pre-instructional stage.

5.2.2 Students' performance in interpreting the changes observed in a physical system after instruction.

Question 2a: For each of the events in the simulation described above: explain as best as you can why they occurred.

Thirteen coding categories were identified which are shown in Table 5.28.

Table 5.28: Categories of responses interpreting the event of the simulation after instruction.

Category number	Category description	Experimental group Freq.	Comparison group Freq.
1	**They happen because there is energy in the elastic store of the compressed spring which is transferred along a mechanical working pathway to the kinetic store of the ball which finally stops moving because energy is degraded.** *'They happen because the spring was compressed by exerting a force.* - *It acquired an elastic store.* - *It is transmitted to the kinetic store of the ball along a mechanical working pathway.* - *It stopped because energy was degraded.'*	1/18	0/18
2	**They happen because there is energy in the elastic store of the compressed spring which is transferred to the kinetic store of the ball and once the ball stops moving, to the internal store of the ball/the air and the ground.** *'The spring was compressed because of the force which we exerted on it and once it was set free it pushed the ball and the energy in the elastic store was transferred and stored in the kinetic store of the ball. In the end the ball stopped because the energy was transferred to the*	6/18	0/18

	internal store of the ground and the air.'		
3	**They happen because there is energy in the elastic store of the compressed spring which is transferred along a mechanical working, heating and sound pathway to the kinetic store of the ball and then to the internal store.** *'The energy is initially stored in the elastic store and in the following is transmitted to the kinetic store along a mechanical working sound and heating pathway and afterwards it is transmitted to the internal store.'*	1/18	0/18
4	**They happen because there is energy in the elastic store of the compressed spring which is transferred along a mechanical working pathway to the kinetic store of the ball.** *'The ball starts moving because the energy stored in the compressed spring (elastic store) is transferred along a mechanical working pathway to the moving ball (kinetic store).'*	7/18	0/18
5	**They happen because there is energy in the compressed spring.** *'They happen because there is compression on the spring and thus there is much energy stored in it. '*	1/18	0/18
6	**They happen because there is force in the compressed spring.** *'It happens because there is compression on the spring and* *the greater the compression exerted on an object the greater the force it acquires.'*	1/18	0/18
7	**They happen because energy is transferred from the spring to the ball.** *'The ball moves because the energy is transferred from the spring to the ball.'*	0/18	4/18
8	**They happen because potential energy is exerted on the ball which is converted into kinetic.** *'At the beginning potential energy is exerted on the ball which in the following is converted into kinetic since the ball was set in motion and afterwards has* (the ball) *stopped because of friction.'*	0/18	1/18
9	**They happen because potential energy in both objects was converted into kinetic.** *'Initially both objects possessed potential energy and in the following when the spring expanded it acquired kinetic energy and so as the ball since the spring pushed it.'*	0/18	1/18
	They happen because energy is released and converted into motion.		

10	*'The energy is released and is converted into motion.'*	0/18	1/18
11	**They happen because force is given by the spring to the ball.** *'The ball needed a force in order to be moved which has been given by the spring when it has been stretched.'*	0/18	2/18
12	**They happen because the spring exerted a force on the ball.** *'The ball moves forward because a force exerted on it by the spring and in the following it stops because of friction.'*	0/18	4/18
13	**No response**	1/18	5/18

As it is shown in the above table, the students interpreted the event of the simulation through referencing energy and force. Thus, a further classification of the coding categories in which the variation of concepts used by students in their interpretations be taken into account could be made as it is shown in Table 5.29.

Table 5.29: Students' performance in formulating an energy description of the event of the simulation after instruction.

Category number	Category description	Experimental group		Comparison group	
		Freq.	Freq. perc. %	Freq.	Freq. perc. %
1	**Interpretation based on energy.**	16/18	88	7/18	39
2	**Interpretation based on other concept:** **-Force**	1/18	6	6/18	33
3	**Interpretation none.**	1/18	6	5/18	28

Results shown in Table 5.29 are also shown in the bar chart of Figure 5.32.

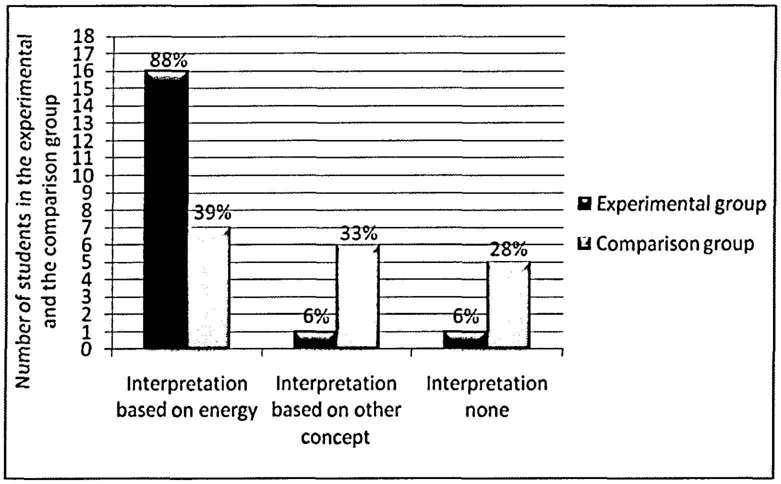


Figure 5.32: Number of students who formulated an energy-based or a non energy-based interpretation of the event of the simulation.

The bar chart clearly suggests a much larger number of students who used energy in their interpretations among those in the experimental group (16), compared that in the comparison group (7). Moreover, it might be of interest these results be compared to the corresponding of pre-instructional stage shown in Figure 5.3. Only one student in the experimental group and four in the comparison group formulated an energy based interpretation at pre-instructional stage; at post-instructional stage, this number was raised to sixteen that is the great majority of the students in the experimental group and respectively to seven, which is less than half of the students in the comparison group.

Results of statistical study concerning the number of students who used energy in the two groups are shown in Table 5.30.

Table 5.30: Results of Fisher's Exact Test about the number of students in the two groups who used energy in their interpretations after instruction.

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	9.753[a]	1	.002		
Continuity Correction[b]	7.706	1	.006		
Likelihood Ratio	10.477	1	.001		
Fisher's Exact Test				.005	.002
N of Valid Cases	36				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.50.

b. Computed only for a 2x2 table

The p value for Fisher's Exact Test is $p=0.005<p_{cutedge}=0.05$. Thus, there is a significant difference in the number of students who used energy in their interpretations between the two groups.

Another issue which might be worth for further investigation and discussion is the number of students who interpreted the changes in the simulation through referencing energy and based their responses on a full and correct, a partially full and correct or an incorrect reasoning. The results revealed concerning the sixteen students in the experimental group and the seven students in the comparison group are shown in Table 5.31.

Table 5.31: Students' performance in formulating an energy description through correct reasoning.

Category number	Category description	Experimental group		Comparison group	
		Freq.	Freq. perc. %	Freq.	Freq. perc. %
1	**Energy based interpretation-Full and correct reasoning.**	8/18	44	0/18	0
2	**Energy based interpretation-Partially full and correct reasoning.**	8/18	44	4/18	22
3	**Energy based interpretation-Incorrect reasoning.**	0/18	0	3/18	17

Results shown in Table 5.31 are also shown in the bar chart of Figure 5.33.

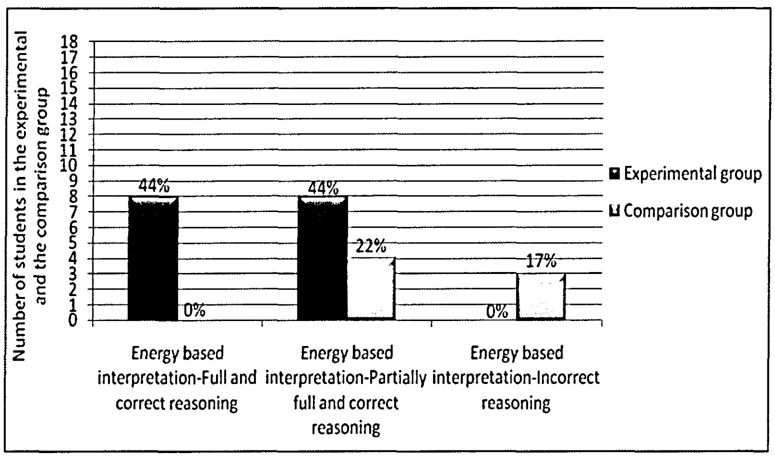


Figure 5.33: Number of students who formulated a full and correct, a partially full and correct or an incorrect energy based interpretation.

The above bar chart clearly suggests that there is a considerable difference in both the number and the quality of responses formulated by the students in the experimental group compared to those in the comparison group. As it can be seen, eight of the sixteen students in the experimental group formulated a full and correct energy description whereas the other eight a partially full and correct one. On the other hand, none of the seven students in the comparison group formulated a full and correct energy description; four formulated a partially full and correct description whereas the other three an incorrect one.

Overall, according to the above results students in the experimental group showed a much higher performance in formulating an energy description compared to that of comparison group at post-instructional stage. Moreover, this improvement seems to be more remarkable for students in the experimental group since at pre-instructional stage only one student formulated a kind of energy description.

5.2.3 Students' views about the energy store at the beginning of a physical process after instruction.

Question 2b: At the very BEGINNING of the simulation event, is there any energy? YES or NO? If YES, where? If NO, why not?

Nine coding categories were identified which are shown in Table 5.32.

Table 5.32: Categories of responses about energy at the beginning of the event of the simulation after instruction.

Category number	Category description	Experimental group	Comparison group
		Freq.	Freq.
1	**Yes. There is energy in the elastic store of the spring.** *'YES. There is in the spring and it is in the elastic store.'*	1/18	0/18
2	**Yes. There is energy in the elastic store.** *'YES. There is an elastic store.'*	4/18	0/18
3	**Yes. There is energy in the compressed spring.** *'Yes. Yes because the spring was compressed.'*	11/18	8/18
4	**Yes. There is energy in the chemical store.** *'Yes. In the chemical store.'*	2/18	0/18
	Yes. There is energy in the ball/the spring and the		

5	**ball.** *'Yes. In the ball.'*	0/18	2/18
6	**Yes. There is energy when the spring hits the ball.** *'Yes. At the point where the spring hits the ball.'*	0/18	2/18
7	**Yes. There is energy.** *'YES.'*	0/18	1/18
8	**No. There isn't any energy because the objects were at rest.** *'NO. Because the ball was at rest and the spring compressed.'*	0/18	3/18
9	**No. There isn't any energy.** *'NO.'*	0/18	2/18

In order to identify the number of students who stated that there is energy in the system at the beginning of the event, coding categories shown in Table 5.32 are classified. The results revealed of this classification are shown in Table 5.33.

Table 5.33: Students' views about energy at the beginning of the event of the simulation after instruction.

Category number	**Category description**	**Experimental group**		**Comparison group**	
		Freq.	**Freq. perc. %**	**Freq.**	**Freq. perc. %**
1	**There is energy at the beginning.**	18/18	100	13/18	72
2	**There isn't energy at the beginning.**	0/18	0	5/18	28

Results shown in Table 5.33 are also shown in the bar chart of Figure 5.34.

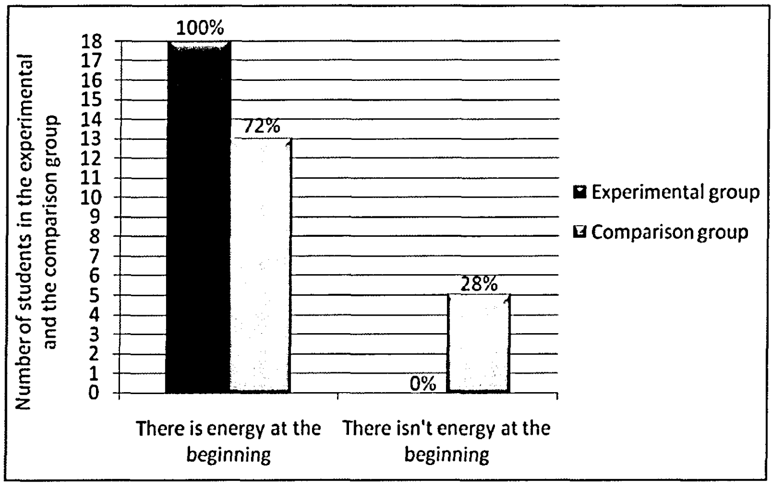


Figure 5.34: Number of students who stated that there is/ isn't energy in the system at the beginning of the event of the simulation.

All students (18) in the experimental group and the great majority (13) in the comparison group stated that there is energy at the beginning of the event. At this point, it might be interesting a further classification of the coding categories in which these students stated that there is energy at the beginning of the event as to whether they have been justified through correct or incorrect reasoning. Thus, the results of this kind of classification are shown in Table 5.34.

Table 5.34: Categories of responses stating and justifying correctly/incorrectly that there is energy at the beginning after instruction.

Category number	Category description	Experimental group		Comparison group	
		Freq.	**Freq. perc. %**	**Freq.**	**Freq. perc. %**
1	**There is energy at the beginning- Correct reasoning.**	16/18	89	8/18	44
2	**There is energy at the beginning- No reasoning.**	0/18	0	1/18	6
3	**There is energy at the beginning- Incorrect reasoning.**	2/18	11	9/18	50

Results shown in Table 5.34 are also shown in the bar chart of Figure 5.35.

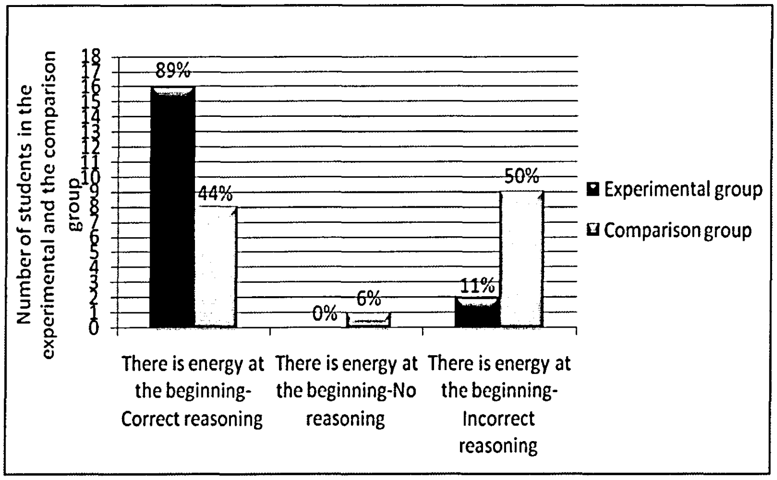


Figure 5.35: Number of students who stated that there is energy in the system at the beginning of the event and justified correctly/incorrectly their statement.

Thus, there is a significant difference in the number of students in the experimental group who stated and justified correctly that there is energy at the beginning of the event compared to the corresponding number in the comparison group. Furthermore the above results are compared with the corresponding revealed at pre-instructional stage shown in Figure 5.6. As it can be seen, the number of students in the experimental group who stated and justified correctly that there is energy at the beginning is much higher at post-instructional stage (16) compared to that at pre-instructional stage (5) whereas for students in the comparison group, the corresponding number is slightly higher (8) compared to that at pre-instructional stage (6).

Moreover, results of statistical study regarding the number of students who stated that there is energy in the system at the beginning and justified correctly in the two groups are shown in Table 5.35.

Table 5.35: Results of Fisher's Exact Test about the number of students in the two groups who stated that there is energy at the beginning after instruction.

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	8.000[a]	1	.005		
Continuity Correction[b]	6.125	1	.013		
Likelihood Ratio	8.540	1	.003		
Fisher's Exact Test				.012	.006
N of Valid Cases	36				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.00.

b. Computed only for a 2x2 table

The *p* value for Fisher's Exact Test is $p=0.012<p_{cutedge}=0.05$. Therefore, there is a significant difference in the number of students who stated that there is energy in the system at the beginning and justified correctly their statement between the two groups.

Overall, results presented earlier suggest a significant difference in understanding of the energy store aspect among students in the experimental group compared to that of students in the comparison group. In addition, comparison of the experimental group students' understanding on the energy store aspect at pre and post-instructional stage implies a considerable improvement.

5.2.4 Students' views about energy store at the end of a physical process after instruction.

Question 3: Think now about the END of the simulation event, when the ball has stopped moving. Is there any energy? YES or NO? If YES, explain. If NO, why not?

Seven coding categories were identified which are shown in Table 5.36.

Table 5.36: Categories of responses about energy at the end of the event of the simulation after instruction.

Category number	Category description	Experimental group	Comparison group
		Freq.	Freq.
1	**Yes. There is energy in the internal store of the ground/the air/the ball/the air and the ground.** *'Yes. Once the ball stopped the energy went to the internal store of the air.'*	11/18	0/18
2	**Yes. There is energy because it is transferred but it is not disappeared.** *'YES. There was energy and after the ball has stopped because energy is simply transferred from one store to another along the transfer pathways and never disappears.'*	3/18	0/18
3	**Yes. There is energy because energy is conserved.** *'Yes. The ball had kinetic energy and once it stopped moving this energy was converted into some other. Energy never disappears! Always it is converted from one energy into*	0/18	6/18

	another.'		
4	**Yes. There is friction and gravity energy.** *'YES.* *Yes there is friction and gravity energy.'*	0/18	1/18
5	**Yes. There is because the ball needs energy to stop.** *'YES.* *Yes, because when the spring expands it pushes the ball which needs energy to stop moving.'*	0/18	1/18
6	**No. There isn't any energy because the ball stopped moving.** *'NO.* *Because the ball stopped moving.'*	1/18	10/18
7	**No. There isn't any energy because there is no energy store.** *'NO.* *There isn't any store and thus there is no energy.'*	3/18	0/18

In order to identify the number of students who stated that there is energy in the system of the simulation at the end of the event, coding categories shown in Table 5.36 are classified. The results of the classification are shown in Table 5.37.

Table 5.37: Students' views about energy at the end of the event of the simulation after instruction.

Category number	Category description	Experimental group		Comparison group	
		Freq.	Freq. perc. %	Freq.	Freq. perc. %
1	There is energy at the end.	14/18	78	8/18	44
2	There isn't energy at the end.	4/18	22	10/18	56

Results shown in Table 5.37 are also shown in the bar chart of Figure 5.36.

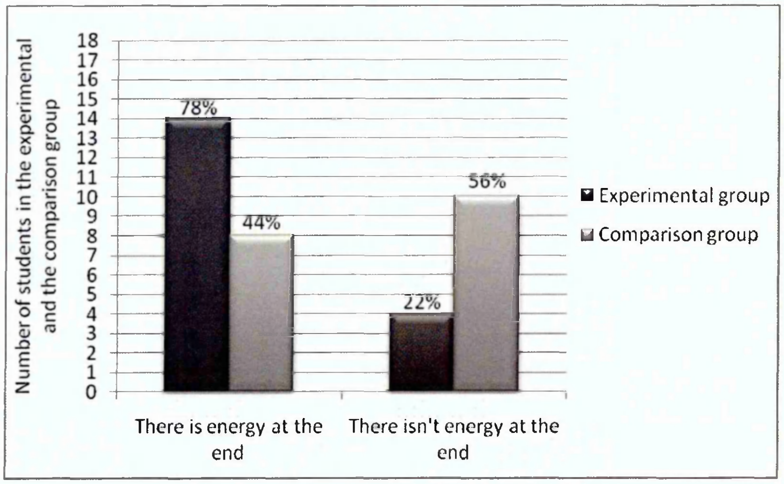


Figure 5.36: Number of students who stated that there is/ isn't energy in the system at the end of the event of the simulation.

At this point, it might be interesting a further classification of the coding categories in which the fourteen students in the experimental group and the eighth students in the comparison group stated that there is energy at the end of the event with respect to whether they were justified through correct or incorrect reasoning. Thus, the results of this kind of classification are shown in Table 5.38.

Table 5.38: Categories of responses stating and justifying correctly/incorrectly that there is energy at the end after instruction.

Category number	Category description	Experimental group		Comparison group	
		Freq.	Freq. perc. %	Freq.	Freq. perc. %
1	**There is energy at the end- Correct reasoning.**	14/18	78	6/18	33
2	**There is energy at the end- Incorrect reasoning.**	0/18	0	2/18	11

Results shown in Table 5.38 are also shown in the bar chart of Figure 5.37.

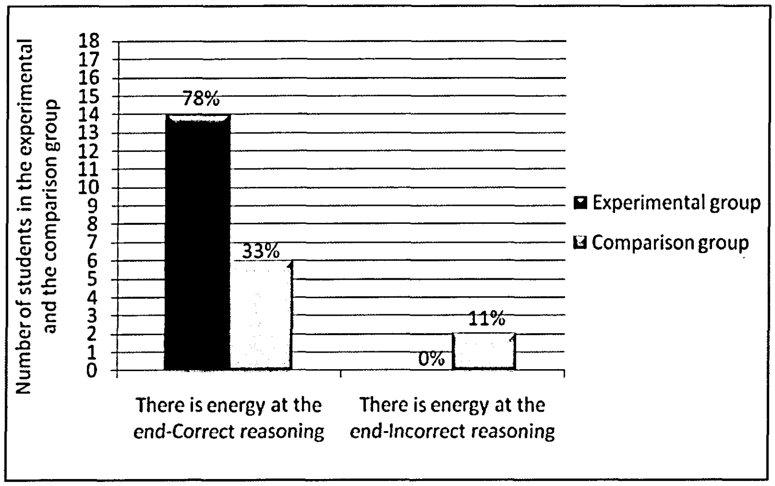


Figure 5.37: Number of students who stated that there is energy in the system at the end of the event and justified correctly/incorrectly their statement.

Results shown in the bar chart clearly suggest that a significantly greater number of students in the experimental group stated and justified correctly that there is energy in the system at the end of the event compared to the corresponding number of students in the comparison group. Furthermore, comparing these results with the corresponding at pre-instructional stage shown in Figure 5.10 it seems that there is a considerable difference for students in the experimental group; at pre-instructional stage, only one student stated that there is energy at the end of the event and justified correctly whereas at post-instructional stage, this number was raised to fourteen. Regarding the students in comparison group, it seems that there is only a slight difference in the results; at pre-instructional stage two students stated and justified correctly that there is energy at the end whereas at post-instructional stage this number was raised to six.

Results of statistical analysis are shown in Table 5.39.

Table 5.39: Results of Fisher's Exact Test about the number of students in the two groups who stated and justified correctly that there is energy at the end after instruction.

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	7.200[a]	1	.007		
Continuity Correction[b]	5.513	1	.019		
Likelihood Ratio	7.477	1	.006		
Fisher's Exact Test				.018	.009
N of Valid Cases	36				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 8.00.

b. Computed only for a 2x2 table

The table shows *p* value for Fisher's Exact Test equal to *p=0.018<p=0.05*. Thus, there is a significant difference in the number of students who stated that there is energy at the end and justified correctly their statement between the two groups.

Overall, the above results suggest a significantly higher understanding of the transfer and conservation aspects of energy among students in the experimental group at post-instructional stage compared to that of students in the comparison group. In addition, comparison of pre and post-instructional stage results revealed a considerable improvement in the experimental group students' understanding of the two aspects compared to that of comparison group students.

5.2.5 Students' views about the aspect of energy conservation after instruction.

Question 4: What can you say about the amount of energy at the BEGINNING compared with the amount of energy at the END?

Five coding categories were identified which are shown in Table 5.40.

Table 5.40: Categories of responses about energy at the beginning and the end after instruction.

Category number	Category description	Experimental group	Comparison group
		Freq.	**Freq.**
1	**The amount of energy at the beginning is the same with the amount of energy at the end.** *'The amount of energy is always the same whatever it happens.'*	15/18	9/18
2	**The amount of energy at the beginning is greater than the amount of energy at the end.** *'The amount of energy at the beginning is greater than the amount of energy at the end.'*	1/18	5/18
3	**There is energy at the beginning but not at the end.** *'At the beginning there is energy in the spring. As the spring pushes the ball the energy is decreased and there isn't any at the end.'*	2/18	0/18
4	**There was no energy at the beginning but there was at the end.** *'At the beginning the amount of energy was zero and*	0/18	2/18

	after the spring expanded and exerted a force on the ball it acquired energy.'		
5	**No response.**	0/18	2/18

In order to identify the number of students who acquired an understanding of the aspect of energy conservation after the experimental intervention, coding categories shown in Table 5.40 are classified. The results of the classification are shown in Table 5.41.

Table 5.41: Students' views about energy conservation after instruction.

Category number	Category description	Experimental group		Comparison group	
		Freq.	Freq. perc. %	Freq.	Freq. perc. %
1	**Energy is conserved.**	15/18	83	9/18	50
2	**Energy is not conserved.**	3/18	17	7/18	39
3	**No response.**	0/18	0	2/18	11

Results shown in Table 5.41 are also shown in the bar chart of Figure 5.38.

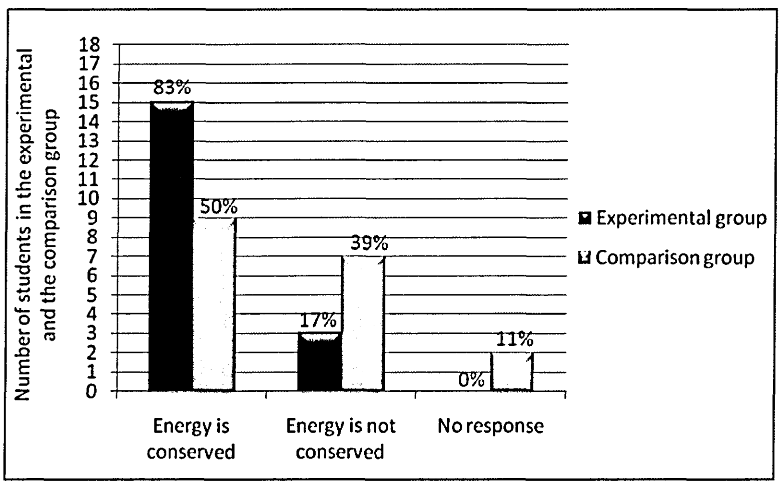


Figure 5.38: Number of students who stated that energy is/is not conserved.

As it is suggested in the bar chart, a significantly greater number of students in the experimental group stated that energy is conserved compared to that in the comparison group. Furthermore, the above results are compared with the corresponding at pre-instructional stage shown in Figure 5.13. Comparison suggests a considerable improvement in the students' understanding in both groups of the conservation of energy aspect. As it is also seen, this improvement is much higher for experimental group since at pre-instructional stage only one student stated that energy is conserved whereas at post-instructional stage, this number was raised to fifteen. Concerning the comparison group, two students stated that energy is conserved at pre-instructional stage whereas at post-instructional stage this number was raised to nine.

Moreover, results of statistical study concerning the number of students who stated that the energy of the system is conserved are shown in Table 5.42.

Table 5.42: Results of Fisher's Exact Test about the number of students in the two groups who stated that energy is conserved after instruction.

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	4.500[a]	1	.034		
Continuity Correction[b]	3.125	1	.077		
Likelihood Ratio	4.656	1	.031		
Fisher's Exact Test				.075	.038
N of Valid Cases	36				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.00.

b. Computed only for a 2x2 table

In the table, p value for Fisher's Exact Test is $p=0.075<p=0.05$. Thus, there is a significant difference in the number of students who stated that the energy of the system is conserved in the two groups.

Overall, the results presented above suggest a significant difference in the experimental group students' understanding of the conservation aspect of energy compared to that of comparison group students. In addition, comparison of pre and post-instructional stage results revealed a higher improvement in the experimental group students' understanding of the aspect compared to that of comparison group students.

5.2.6 Students' performance in formulating an energy description of a physical process which takes place in a physical system after instruction.

Question 5: Finally, describe overall what has happened to the energy of the event from BEGINNING to END.

Ten coding categories were identified which are shown in Table 5.43.

Table 5.43: Categories of responses formulating a scientifically or an alternative oriented energy description after instruction.

Category number	Category description	Experimental group Freq.	Comparison group Freq.
	Scientifically oriented energy description. **-The 'New' energy conceptual framework.**		
1	- The energy in the elastic store is transferred along a mechanical working pathway to the kinetic store and along a heating and a sound pathway to the internal store. *'At the beginning we have an elastic store and it is transferred along a mechanical working pathway to the kinetic store and along a heating and sound pathway it went to the internal store.'*	2/18	0/18
2	- The energy in the elastic store of the spring is transferred along a mechanical working pathway to the kinetic store of the ball and along a heating pathway to the internal store of the atmosphere/the air/the ball. *'At the beginning the energy is in the elastic store of the spring and hence it is transferred to the kinetic store of the ball along a mechanical working pathway and then along a heating pathway to the internal store of the atmosphere.'*	5/18	0/18
3	- The energy in the elastic store of the spring is transferred along a mechanical working pathway to the kinetic store of the ball and then to the internal store of the air and the ground/to the internal store. *'The energy was in the elastic store of the spring and hence it was transferred along a mechanical working pathway to the kinetic store of the ball then to the internal store of the air and the earth.'*	5/18	0/18
4	- The energy in the elastic store is transferred to the kinetic store along a mechanical working pathway. *'At the beginning there is energy in the elastic store of the spring which is transferred along a mechanical working pathway to the kinetic store.'*	6/18	0/18
	- The 'Forms' of energy conceptual framework.		
5	- At the beginning there was potential energy which converted to kinetic and afterwards to heat energy because of friction. *'At the beginning energy was potential in the following it was converted to kinetic and afterwards to heat energy because of friction which made the ball to stop.'*	0/18	3/18

6	- Energy was converted into kinetic. *'The energy was converted into kinetic regarding with the beginning.'*	0/18	3/18
7	**- The 'Conservation' of energy conceptual framework.** - Energy remained the same. *'Energy remains the same at the beginning and at the end.'*	0/18	3/18
8	**'Alternative' oriented energy description.** **- The 'activity' energy model.** - The energy is transferred to the ball which stops when another energy is exerted on it. *'At the beginning the energy is transferred to the ball and then another energy is exerted and stops the ball. $F_{total}=0$.'*	0/18	1/18
	- The 'product' energy model. - At the beginning there wasn't energy, then there was and at the end there wasn't. *'At the beginning there wasn't energy, it acquired in the following and at the end there wasn't.'*	0/18	2/18
10	**No response.**	0/18	6/18

Results shown in the above table are presented in the bar chart of Figure 5.39.

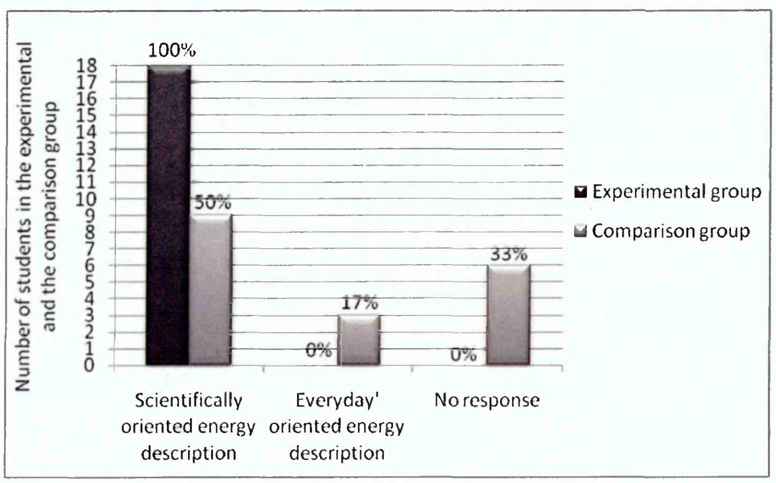


Figure 5.39: Number of students who formulated a scientific or an alternative oriented energy description.

Thus, there is a considerable difference in the number of students in the experimental group who formulated a scientifically oriented energy description of the event of the simulation compared to that in comparison group. This seems to point towards a better understanding of the energy concept among students in the experimental group compared to that of comparison group. Furthermore, comparison of these results with the corresponding at pre-instructional stage shown in Figure 5.15 suggests a remarkable improvement in the experimental group students' understanding of the energy concept; at pre-instructional stage only one student formulated a scientifically oriented energy description whereas at post-instructional stage all eighteen students did so. Regarding the comparison group, comparison suggests some improvement in the students' understanding of the energy concept; at pre-instructional stage two students formulated a scientifically oriented energy description whereas at post-instructional stage this number was raised to nine. In addition, six students who did not respond at pre-instructional stage also failed to formulate an energy description at post-instructional stage.

Focusing on the coding categories shown in Table 5.43 in which the eighteen students in the experimental group and the nine students in the comparison group formulated a scientifically oriented energy description, a further classification could be made according to the energy conceptual framework used. The results of this kind of classification are shown in Table 5.44.

Table 5.44: Categories of responses formulating an energy description according to the 'New'/'Forms'/'Conservation' conceptual framework.

Category number	Category description	Experimental group		Comparison group	
		Freq.	Freq. perc. %	Freq.	Freq. perc. %
1	**The 'New' energy conceptual framework.**	18/18	100	0/18	0
2	**The 'Forms' of energy conceptual framework.**	0/18	0	6/18	33
3	**The 'Conservation' of energy conceptual framework.**	0/18	0	3/18	17

Results shown in Table 5.44 are presented in the bar chart of Figure 5.40.

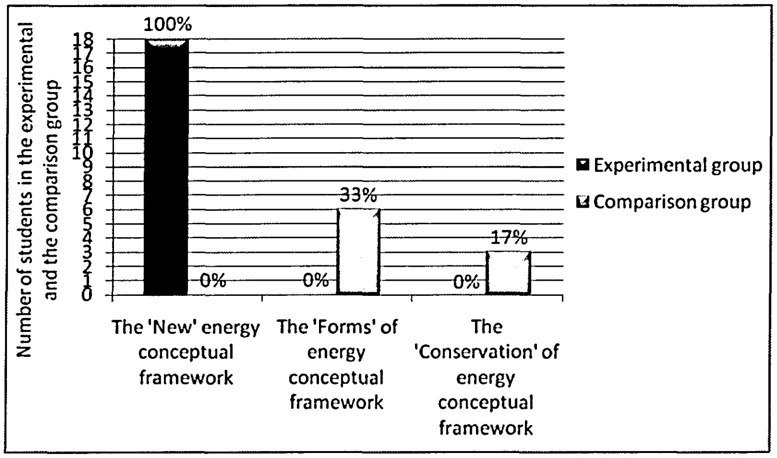


Figure 5.40: Number of students who formulated an energy description according to the 'New'/'Forms'/'Conservation' conceptual framework.

Thus, all eighteen students in the experimental group formulated an energy description (full or partially full, as discussed in section 5.2.2) using the ideas and the terminology of the 'new' energy framework introduced. On the other hand, only six students in comparison group formulated an energy description according to the 'forms' of energy framework taught. This seems to provide further evidence of a better improvement in the experimental group students' understanding of the energy concept compared to that of comparison group.

In the following, coding categories shown in Table 5.43 are further examined with respect to the students' understanding of the degradation aspect of energy. The results of this kind of classification are shown in Table 5.45.

Table 5.45: Students' views about energy conservation after instruction.

Category number	Category description	Experimental group		Comparison group	
		Freq.	Freq. perc. %	Freq.	Freq. perc. %
1	At the end, energy stored in an internal store.	12/18	67	0/18	0
2	At the end, energy transformed to heat.	0/18	0	3/18	17
3	At the end, energy stored in a kinetic store/transformed to kinetic.	6/18	33	3/18	17

4	**At the end, energy remained the same/consumed.**	0/18	0	6/18	33
5	**No response.**	0/18	0	6/18	33

Results shown in Table 5.45 are also shown in the bar chart of Figure 5.41.

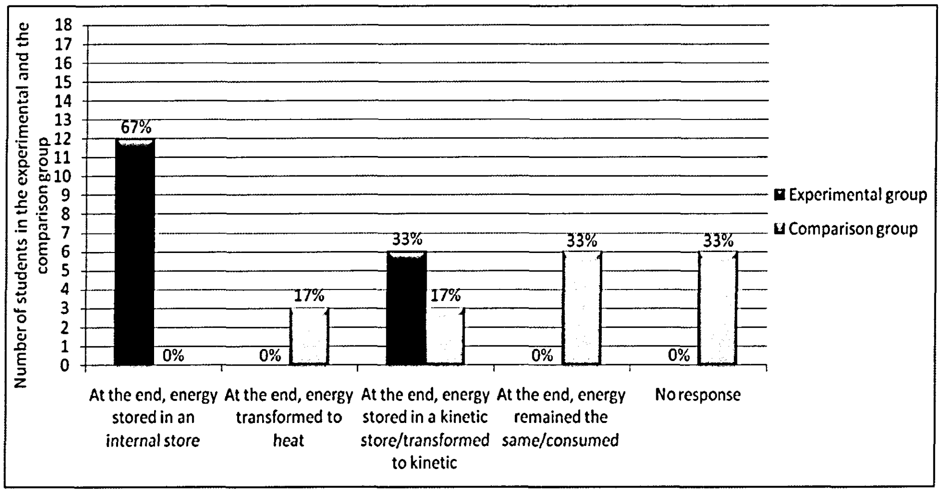


Figure 5.41: Number of students who stated that energy is/is not degraded.

The bar chart shows a significant difference in the number of students in the experimental group (12) who stated that the energy of the system is degraded compared to that in the comparison group (3). The above results suggest a better understanding of the degradation of energy aspect among students in the experimental group compared to that among students in the comparison group. Furthermore, comparison of these results to the corresponding at pre-instructional stage shown in Figure 5.41 reveals a considerable improvement in the experimental group students' understanding of the degradation of energy aspect whereas for students in the comparison group a slight one. As it is seen, at pre-instructional stage only one student in the experimental group stated that the energy of the system is degraded; at post-instructional stage this number was raised to twelve. Concerning the comparison group, none of the students stated that the energy of the system is degraded at pre-instructional stage whereas at post-instructional stage this number was raised to three students.

Results of statistical study concerning the number of students who stated that the energy of the system is degraded are shown in Table 5.46.

Table 5.46: Results of Fisher's Exact Test about the number of students in the two groups who stated that energy is degraded after instruction.

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	9.257[a]	1	.002		
Continuity Correction[b]	7.314	1	.007		
Likelihood Ratio	9.767	1	.002		
Fisher's Exact Test				.006	.003
N of Valid Cases	36				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 7.50.

b. Computed only for a 2x2 table

The *p* value for Fisher's Exact Test is $p=0.006<p=0.05$. Therefore, there is a significant difference in the number of students who stated that the energy of the system is degraded between the two groups.

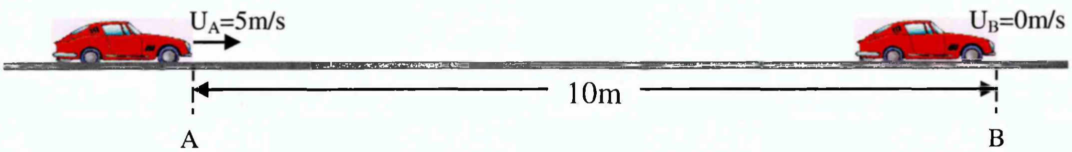
Overall, according to the results presented above it seems that there is a considerable difference in the experimental group students' understanding of the energy concept compared to that of students in the comparison group at post-instructional stage. In addition, comparison of pre and post-instructional stage results suggest a higher improvement in the experimental group students' understanding of the energy concept compared to that of comparison group students.

Regarding the post-instructional stage results on the degradation of energy aspect, they suggest a significant difference in the experimental group students' understanding compared to that of comparison group students. Furthermore, comparison of pre and post-instructional stage results reveal a considerable improvement in understanding of the degradation of energy aspect among students in the experimental group compared to that among students in the comparison group.

PART B

5.2.7 Students' ability in transferring the acquired knowledge on the energy concept in novel physical systems and to apply it to numerical problems.

Question 1: *A car of mass 800kg is traveling along the road with a constant speed of 5m/s.*



At point A, it runs out of petrol and its engine stops working. The car moves for another 10m before finally stopping at point B.

Sub-question 1a: *Was any energy stored in the system at point A? Answer YES/NO. If YES, name that energy and calculate how much there is.*

Eight coding categories were identified which are shown in Table 5.47.

Table 5.47: Categories of responses about the amount of energy at the beginning of the event of the first image.

Category number	Category description	Experimental group	Comparison group
		Freq.	**Freq.**
1	**Yes. There is energy in the kinetic store-Correct result.** *'Yes.* *Kinetic store.* $K=\frac{1}{2}mu^2=\frac{1}{2}800(5)^2$ $=10000J$	17/18	0/18
2	**Yes. There is energy in the kinetic store-False result.** *'YES.* *Kinetic store.* $K=\frac{1}{2}mu^2$, $=\frac{1}{2}.10.25=125J$	1/18	0/18
	Yes. There is kinetic energy-Correct result.		

3	*'Yes.* *Kinetic energy.* $K = \frac{1}{2}mu^2 = \frac{1}{2}800(5)^2$ $= 10000J$	0/18	7/18
4	**Yes. There is energy, its petrol.** *'YES.* *There is petrol and so moves for another 10m.'*	0/18	1/18
5	**Yes, there is energy.** *'YES'.*	0/18	5/18
6	**No. There isn't any energy because there is no petrol.** *'NO.* *The car moves for a short distance even without petrol before it stops.'*	0/18	1/18
7	**No. There isn't any energy because the car is not moving.** *'NO.* *Because the car stopped.'*	0/18	3/18
8	**No response.**	0/18	1/18

In order to identify the number of students who stated that there is energy in the system at the beginning of the physical process which takes place in it, that is, at point A, coding categories shown in Table 5.47 are classified. The results of this kind of classification are shown in Table 5.48.

Table 5.48: Students' views about energy at the beginning of the event of the first image.

Category number	Category description	Experimental group		Comparison group	
		Freq.	Freq. perc. %	Freq.	Freq. perc. %
1	**There is energy at point A.**	18	100	13	72
2	**There isn't energy at point A.**	0	0	4	22
3	**No response.**	0	0	1	6

Results shown in Table 5.48 are also shown in the bar chart of Figure 5.42.

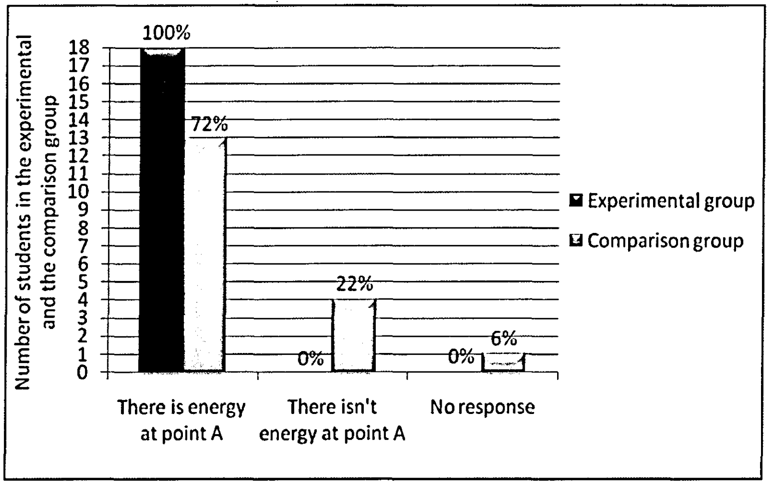


Figure 5.42: Number of students who stated that there is/isn't energy in the system at the beginning of the event of the image.

A greater number of students in the experimental group (18) stated that there is energy at the beginning of the event compared to the corresponding number of those in the comparison group (13).

Also, it might be of interest a further classification of the coding categories in which the eighteen students in the experimental group and the thirteen students in the comparison group stated that there is energy at point A, as to whether they were justified through correct or incorrect reasoning. Thus, the results of this kind of classification are shown in Table 5.49.

Table 5.49: Categories of responses stating and justifying correctly/incorrectly that there is energy at the beginning of the event of the image.

Category number	Category description	Experimental group		Comparison group	
		Freq.	Freq. perc. %	Freq.	Freq. perc. %
1	**There is energy at point A-Correct reasoning.**	18/18	100	7/18	39
2	**There is energy at point A-No reasoning.**	0/18	0	5/18	28
3	**There is energy at point A-Incorrect reasoning.**	0/18	0	1/18	6

Results shown in Table 5.49 are also shown in the bar chart of Figure 5.43.

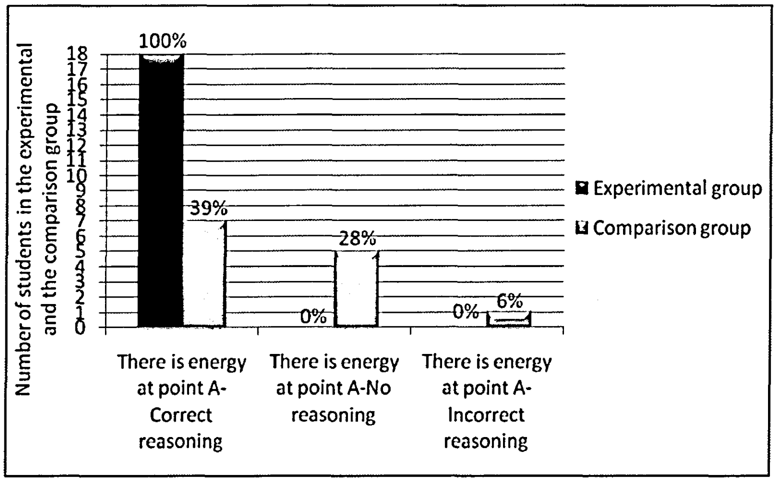


Figure 5.43: Number of students who stated that there is energy in the system at the beginning and justified correctly/incorrectly their statement.

As it is seen in the bar chart, all eighteen students in the experimental group and only seven students in the comparison group stated that there is energy at point A in the kinetic store and used correctly the formula to calculate the amount in it. These results suggest both a better understanding of the energy store aspect and a better ability in transferring this knowledge in this system among students in the experimental group compared to that in the comparison group.

Sub-question 1b: *What has happened to that* ***amount*** *of energy at point B? Compare it to that at point A. In what they are similar and in what they differ? Justify your answer.*

Six coding categories were identified which are shown in Table 5.50.

Table 5.50: Categories of responses about the amount of energy at the beginning and the end of the event of the first image.

Category number	**Category description**	**Experimental group**	**Comparison group**
		Freq.	**Freq.**
1	**The amount of energy at point B is the same with the amount of energy at point A. At point A energy was in a kinetic store whereas at point B in an internal store.** *'The amount of energy was transferred to the internal store of the ground. The two amounts of energy are similar to the fact that they are the same because energy is not disappeared but it is transferred somewhere else and they differ to the fact that the energy at B is not in the kinetic store of the car.'*	14/18	0/18

2	**The amount of energy at point B is the same with the amount of energy at point A. They differ in the kind of 'form'.** *'It is the same amount. They are the same in the amount but not to the kind of energy because energy is always converted into a different kind but always remains the same.'*	0/18	4/18
3	**The amount of energy at point B is the same with the amount of energy at point A.** *'It is the same amount.'*	2/18	0/18
4	**There is no energy at point B because the car stopped at that point.** *'The amount of energy at point B is zero compared to that at point A where the car still moves.'*	2/18	4/18
5	**The amount of energy at point B is greater than the amount of energy at point A.** *'The amount of energy increased at B.'*	0/18	2/18
6	**No response.**	0/18	8/18

At this point, it might be interesting to identify the number of students who stated that the energy of the system is conserved. The results of this kind of classification are shown in Table 5.51.

Table 5.51: Students' views about the conservation of the energy of the system of the first image.

Category number	Category description	Experimental group		Comparison group	
		Freq.	Freq. perc. %	Freq.	Freq. perc. %
1	**Energy is conserved.**	16/18	89	4/18	22
2	**Energy is not conserved.**	2/18	11	6/18	33
3	**No response.**	0/18	0	8/18	45

Results shown in Table 5.51 are also shown in the bar chart of Figure 5.44.

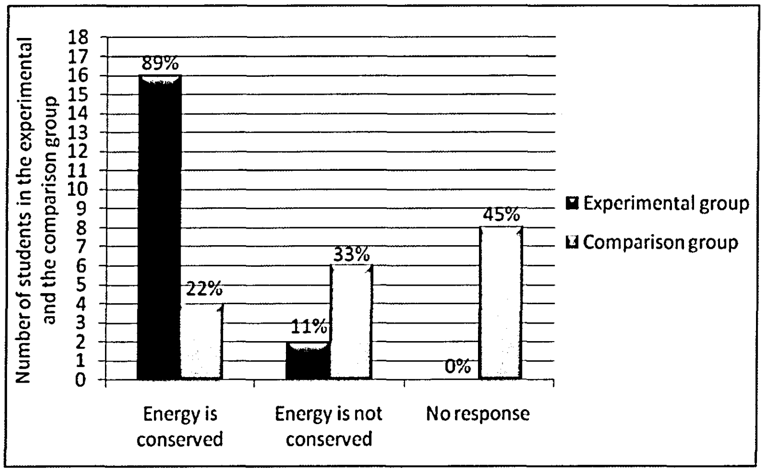


Figure 5.44: Number of students who stated that energy is/is not conserved.

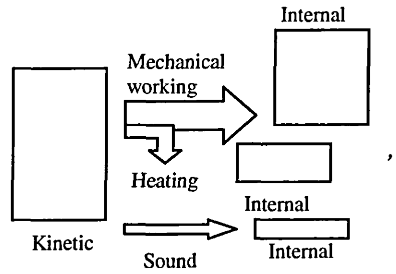
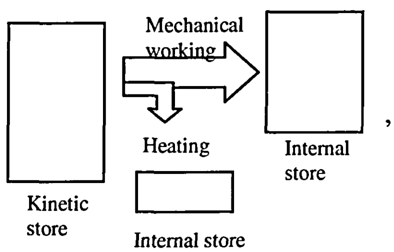
The above bar chart clearly shows a considerable difference in the number of students in the experimental group (16) who stated that the energy of the system is conserved compared to those in the comparison group (4). These results provide evidence for both a better understanding of the conservation of energy aspect and a better ability in transferring this knowledge in this system among students in the experimental group compared to that in comparison group.

Sub-question 1c: *Describe in words or in any other way and in much detail as you can, what has happened to the energy of the system from point A to point B.*

Twelve coding categories were identified which are shown in Table 5.52.

Table 5.52: Categories of responses formulating an energy description of the event of the first image.

Category number	Category description	Experimental group Freq.	Comparison group Freq.
1	**The energy in the chemical store is transferred along a mechanical working pathway to the kinetic store and along a heating and a sound pathway to the internal store.** *At the beginning energy is in the chemical store of the petrol which is transferred along a mechanical working pathway to the kinetic store and then it is degraded along a sound and a heating pathway to the internal store.'*	1/18	0/18
2	**The energy in the kinetic store is transferred along a heating pathway to the internal store.** *'The kinetic store at A is transferred along a heating pathway to the internal store of the environment since at point B the car stops and its kinetic store is*	1/18	0/18

	transferred to the internal store of the environment.'		
3	**Kinetic energy was transformed to heat energy.** *'At point A kinetic energy changed into heat energy because of friction which stopped the car.'*	0/18	2/18
4	**The energy in the kinetic store is transferred along a mechanical working, a heating and a sound pathway to the internal store.** '  ' 	4/18	0/18
5	**The energy in the kinetic store is transferred along a mechanical working and a heating pathway to the internal store.** '  ' 	2/18	0/18
6	**The energy in the kinetic store is transferred along a mechanical working pathway to the internal store.** *'The energy was in the kinetic store of the car and it was transferred along a mechanical working pathway to the internal store of the air and the ground.'*	4/18	0/18
7	**The energy in the chemical store is transferred to the kinetic store.** *'Initially we have it in a chemical store and it is transferred along a mechanical working pathway to the kinetic store.'*	3/18	0/18
8	**The energy in the kinetic store at point A run out at point B.** *'Initially at A the car still had a kinetic store which retained for the distance of 10m where the kinetic store run out. '*	2/18	0/18
9	**Kinetic energy was transformed into potential energy.** *'Kinetic energy is changed into potential.'*	0/18	1/18
10	**Kinetic energy was transformed into another energy form.**	0/18	1/18

	'Kinetic became some other form of energy.'		
11	**The energy decreased once petrol run out.** *'At point A there was much energy but decreased once petrol run out which produces energy in order the car to move.'*	0/18	3/18
12	**No response.**	1/18	11/18

In studying the above table, some interesting issues are raised. As it is seen, twelve students, that is the majority of the students in the experimental group, recognized correctly the energy transfer from the initial kinetic store to the final internal store (categories 1, 2, 4, 5 and 6). This provides evidence of an understanding of the transfer aspect of energy and an ability in transferring the acquired knowledge in this system. However, it should be noted that there is some confusion concerning the transfer pathway along which the energy is transferred to the internal store; mechanical working is specified along with heating (categories 4, 5 and 6). Regarding the comparison group students, none of them used the transfer aspect, though two students stated that the kinetic energy is transformed at the end to heat (category 3). Furthermore, the majority of the students in the comparison group failed to formulate an energy description of the physical process. This suggests little understanding of the energy concept among students in the comparison group.

In order to identify the number of students who stated that the energy of the system is degraded, coding categories shown in Table 5.52 were classified. The results of this kind of classification are shown in Table 5.53.

Table 5.53: Students' views about the degradation of the energy of the system of the first image.

Category number	Category description	Experimental group		Comparison group	
		Freq.	**Freq. perc. %**	**Freq.**	**Freq. perc. %**
1	**Energy is degraded.**	12/18	67	2/18	11
2	**Energy is not degraded.**	5/18	27	5/18	27
3	**No response.**	1/18	6	11/18	62

Results shown in Table 5.53 are also shown in the bar chart of Figure 5.45.

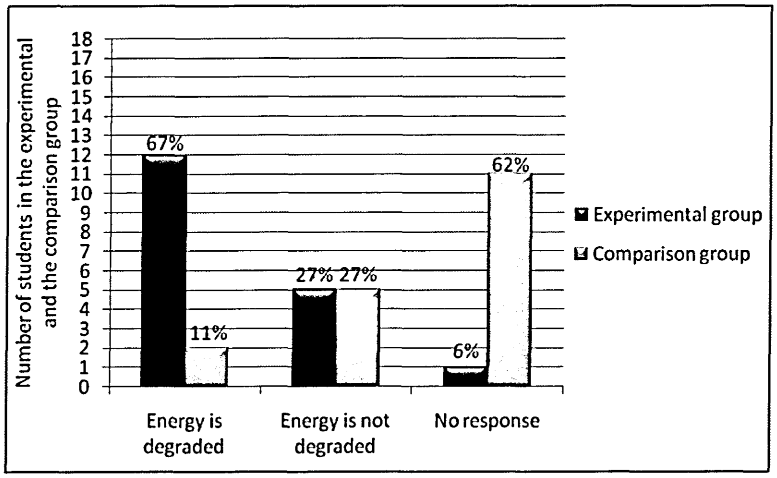


Figure 5.45: Number of students who stated that energy is/is not degraded.

Thus, there is a considerable difference in the number of students who stated that the energy of the system is degraded in the experimental group (12) compared to that in the comparison group (2). These results suggest ability in transferring the acquired knowledge on the degradation of energy aspect in this system among students in the experimental group.

Sub-question 1d: *Calculate the force (F) between the wheels of the car and the road in order the car to stop at point B.*

Three coding categories were identified which are shown in Table 5.54.

Table 5.54: Categories of responses in which the mechanical working-kinetic store theorem is used.

Category number	Category description	Experimental group Freq.	Comparison group Freq.
1	**Correct reasoning-Correct result.** $W = F.x \Rightarrow 10000 = F.10$ $\Rightarrow F = -1000N$ $W = \Delta K \Rightarrow W = K_2 - K_1 = 10000$	14/18	0/18
2	**False reasoning-False result.** $F = m.a \Rightarrow K = m.a.x$ $W = F.x =$	1/18	3/18
3	**No response.**	3	15

Results shown in Table 5.54 are also shown in the bar chart of Figure 5.46.

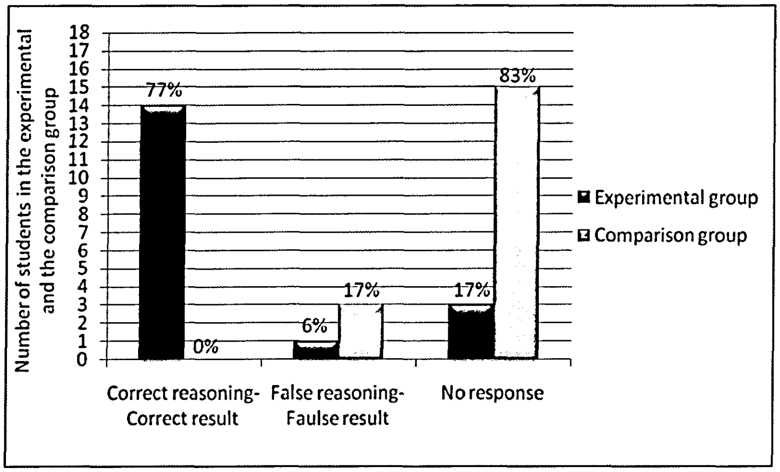
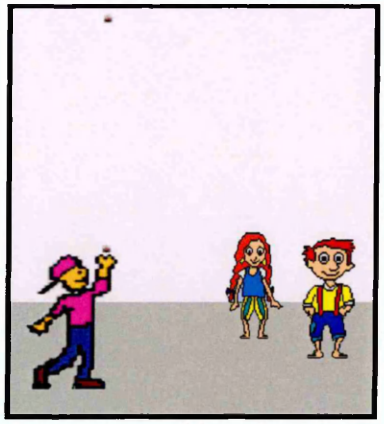


Figure 5.46: Number of students who used correctly/incorrectly the mechanical working-kinetic store theorem.

The bar chart clearly suggests that there isn't an understanding of the mechanical working-kinetic store theorem among students in the comparison group since the great majority did not respond to the question and the few who attempted to respond used a false reasoning. This result could be justified by the fact that the mechanical working-kinetic store theorem was not taught by the comparison group teacher even though it is included in the Cyprus National Curriculum for Physics for the first grade of high school. Also, the bar chart suggests that there is a good understanding of the theorem among students in the experimental group (14) since the great majority applied it correctly.

Overall, results presented above suggest a good understanding of the energy ideas of store, transfer, conservation and degradation among students in the experimental group whereas little understanding for students in the comparison group. Furthermore, students in the experimental group showed ability in transferring the acquired knowledge on the energy ideas both qualitatively and quantitatively in this system whereas for students in the comparison group, this ability seems to be limited.

Question 2: *George makes a bet with his friends Helena and John that he can throw a coin up to a height of 5m.*



Sub-question 2a: *As the coin moves up through the air it has kinetic energy. Where does it get this energy from?*

Seven coding categories were identified which are shown in Table 5.55.

Table 5.55: Categories of responses about the amount of energy at the beginning of the event of the second image.

Category number	Category description	Experimental group	Comparison group
		Freq.	Freq.
1	**The coin gets the energy from the chemical store of the boy.** *'Energy was transferred from the chemical store of George to the kinetic store of the coin.'* and *'Initially we have it in a chemical store and along a mechanical working pathway is stored in a kinetic store.'*	12/18	0/18
2	**The coin gets the energy from the boy.** *'It gets the energy from George.'*	2/18	5/18
3	**The coin has potential energy which is converted to kinetic.** *'At the beginning it had* (the coin) *potential energy which it was converted to kinetic since it started* (the coin) *to move.'*	0/18	2/18
4	**The coin gets the energy from the speed that the boy gave it.**	3/18	0/18

	'From the speed which the boy gave it exerting a force on it.'		
5	**The coin gets energy because it moves.** *'It moves upwards.'*	0/18	2/18
6	**The coin gets the energy from the force that the boy gave it.** *'It got this energy from the force that the boy gave it.'*	0/18	5/18
7	**No response.**	1/18	4/18

In order to identify the number of students who stated that there is energy at the beginning of the process, coding categories shown in Table 5.55 are categorized. The results of this kind of classification are shown in Table 5.56.

Table 5.56: Students' views about energy at the beginning of the event of the second image.

Category number	Category description	Experimental group		Comparison group	
		Freq.	**Freq. perc. %**	**Freq.**	**Freq. perc. %**
1	**There is energy at the beginning.**	14/18	78	5/18	28
2	**There isn't energy at the beginning.**	3/18	16	9/18	50
3	**No response.**	1/18	6	4/18	22

Results shown in Table 5.56 are also shown in the bar chart of Figure 5.47.

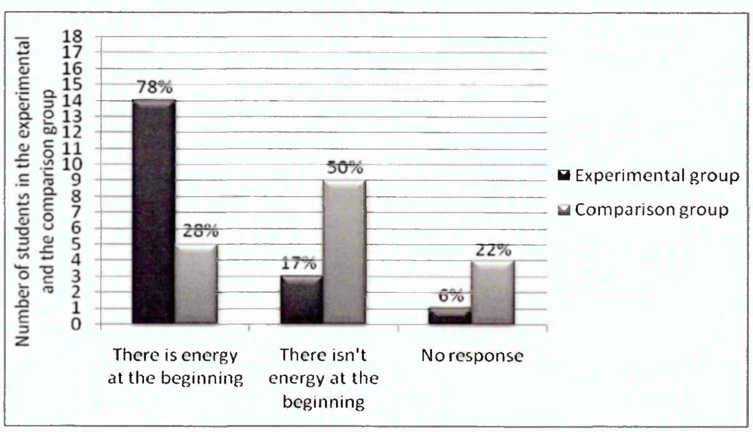


Figure 5.47: Number of students who stated that there is/isn't energy at the beginning of the event of the image.

Thus, the great majority of the students in the experimental group (14) and a small number in the comparison group (5) stated that there is energy in the system at the beginning of the process. These results suggest a good ability in transferring the acquired knowledge on the energy store aspect for students in the experimental group and little ability for students in the comparison group.

Also, it might be interesting a further classification of the coding categories in which the fourteen students in the experimental group and the five students in the comparison group stated that there is energy at the beginning of the physical process with respect to whether they recognized the chemical store of the boy as the place in which energy was found. Thus, the results of this kind of classification are shown in Table 5.57.

Table 5.57: Categories of responses about the place at which energy is initially stored.

Category number	Category description	Experimental group		Comparison group	
		Freq.	Freq. perc. %	Freq.	Freq. perc. %
1	**There is energy at the beginning in the chemical store of the boy.**	12/18	67	0/18	0
2	**There is energy at the beginning in the boy.**	2/18	11	5/18	28

Results shown in Table 5.57 are also shown in the bar chart of Figure 5.48.

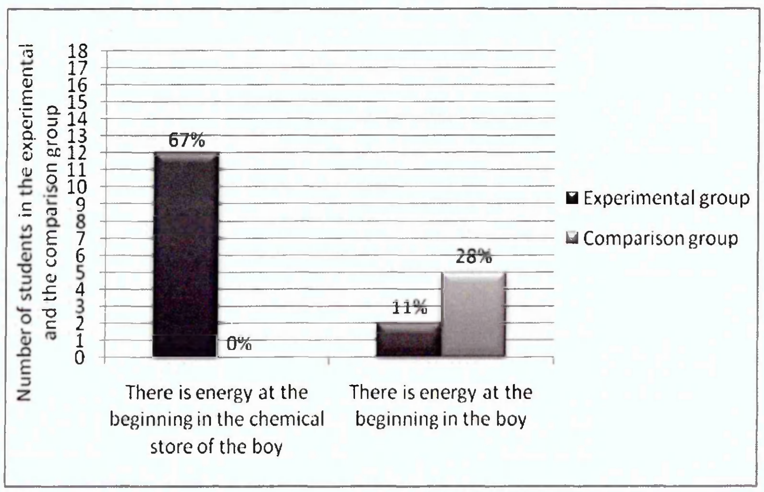


Figure 5.48: Number of students who stated that there is energy in the chemical store.

In the above bar chart, none of the students in the comparison group stated that at the beginning there was energy in the chemical store of the boy. This result could be fully justified by the fact that in the Cyprus National Curriculum for Physics for the first grade of high school, the 'form' chemical energy is not included; however, the chemical energy idea is introduced in the second grade of lower secondary school. Furthermore, the majority of the students in the experimental group recognized correctly the chemical store of the boy as the place in which the energy of the system was initially found.

Sub-question 2b: *At the top of its flight the coin is stationary for a moment. Where is the energy now?*

Five coding categories were identified which are shown in Table 5.58.

Table 5.58: Categories of responses about energy at the end of the event of the second image.

Category number	Category description	Experimental group	Comparison group
		Freq.	Freq.
1	**Yes. There is energy in a gravitational store.** *'Yes there is. The energy goes to the gravitational store.'*	6/18	0/18
2	**Yes. There is potential energy.** *'Yes. Potential energy.'*	0/18	3/18
3	**Yes. There is energy.** *'Yes always there is energy.'*	10/18	12/18
4	**No. There isn't any energy.** *'No there isn't any energy.'*	2/18	2/18
5	**No response.**	0/18	1/18

In order to identify the number of students who stated that there is energy at the top of the coin's flight, coding categories shown in Table 5.58 are categorized. The results of this kind of classification are shown in Table 5.59.

Table 5.59: Students' views about energy at the end of the event of the second image.					
Category number	**Category description**	**Experimental group**		**Comparison group**	
		Freq.	**Freq. perc. %**	**Freq.**	**Freq. perc. %**
1	**There is energy at the top of the coin's flight.**	16/18	89	15/18	83
2	**There isn't energy at the top of the coin's flight.**	2/18	11	2/18	11
3	**No response.**	0/18	0	1/18	6

Results shown in Table 5.59 are also shown in the bar chart of Figure 5.49.

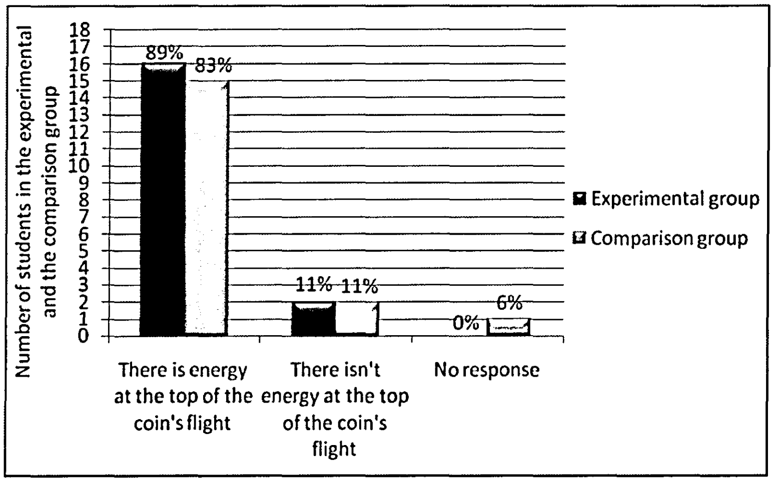


Figure 5.49: Number of students who stated that there is/isn't energy at the top of the coin's flight.

Thus, the great majority of the students in the experimental (16) and the comparison group (15) stated correctly that there is energy at the top of the coin's flight. These results suggest a good understanding of the aspect of energy transfer and an ability in transferring this knowledge in this system.

Sub-question 2c: *Calculate the energy of the coin when it reaches the height of 5m (the mass of the coin is 0.003Kg and g=10m/s^2).*

Three coding categories were identified which are shown in Table 5.60.

Table 5.60: Categories of responses about the amount of energy at the end of the event of the second image.

Category number	Category description	Experimental group	Comparison group
		Freq.	**Freq.**
1	**Correct reasoning-Correct result.** '$G = m.g.h = 0.003 \times 10 \times 5 = 0.15J$ '	18/18	12/18
2	**False reasoning-False result.** '$0.003Kg \times 5m =$ '	0/18	1/18
3	**No response.**	0/18	5/18

Results shown in Table 5.60 are also shown in the bar chart of Figure 5.50.

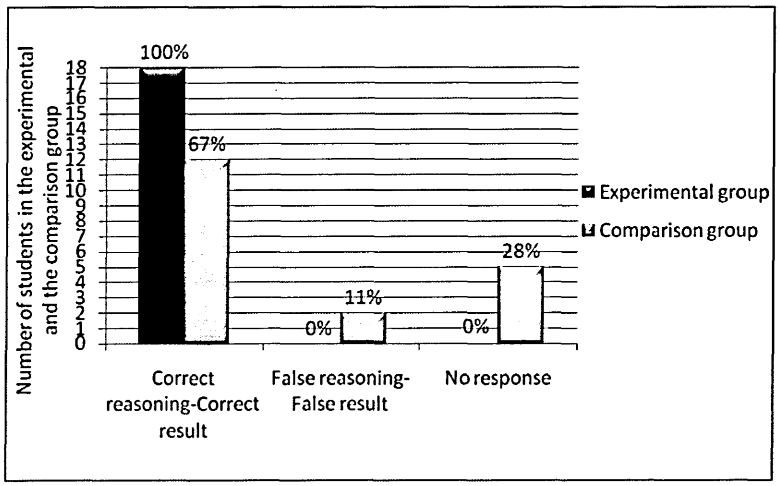


Figure 5.50: Number of students who stated that there is energy at the top of the coin's flight and justified correctly/incorrectly their response.

In the above bar chart, all eighteen students in the experimental group and twelve in the comparison group, that is the majority, stated correctly that the energy of the system at the top of the coin's flight is in the gravitational store/in the 'form' of gravitational potential energy and used correctly the formula to calculate that amount. Furthermore, comparison of these results with those in Table 5.59 reveals that two students in the experimental group although they stated that there isn't any energy at the top of the coin's flight, proceed to the correct calculation of the amount of energy of the gravitational store. This result might be interpreted by lack of understanding of the conservation aspect of energy and solely the application of data on the calculating formula of gravitational store.

***Sub-question 2d**: Taking account of the energy at the 5m height, which you have just calculated: calculate the initial speed of the coin as it leaves George's hand.*

Five coding categories were identified which are shown in Table 5.61.

Table 5.61: Categories of responses in which the conservation of mechanical store theorem is used.

Category number	Category description	Experimental group	Comparison group
		Freq.	Freq.
1	**Correct reasoning-Correct result.** ‘$G_2 = K_1 \Rightarrow G = \frac{1}{2}mu^2$ $0.15 = \frac{1}{2}(0.003)u^2 \Rightarrow u^2 = 100$’ $u = 10 \, {}^{m}\!/_{s}$	7/18	1/18
2	**Correct reasoning-False result.** ‘$K = \frac{1}{2}mu^2$ $K = G \Rightarrow K = 0.15$’ $0.15 = \frac{1}{2}0.003u^2$ $u^2 = \frac{1}{100} \Rightarrow 0.01 = u^2$ $= 0.1$	9/18	0/18
3	**Correct reasoning-No result.** *‘W_A=W_E=0,15*	0/18	2/18
4	**False reasoning-No result.** *‘Its speed before it leaves George's hand is 0.’*	1/18	1/18
5	**No response.**	1/18	14/18

Results shown in Table 5.61 are also shown in the bar chart of Figure 5.51.

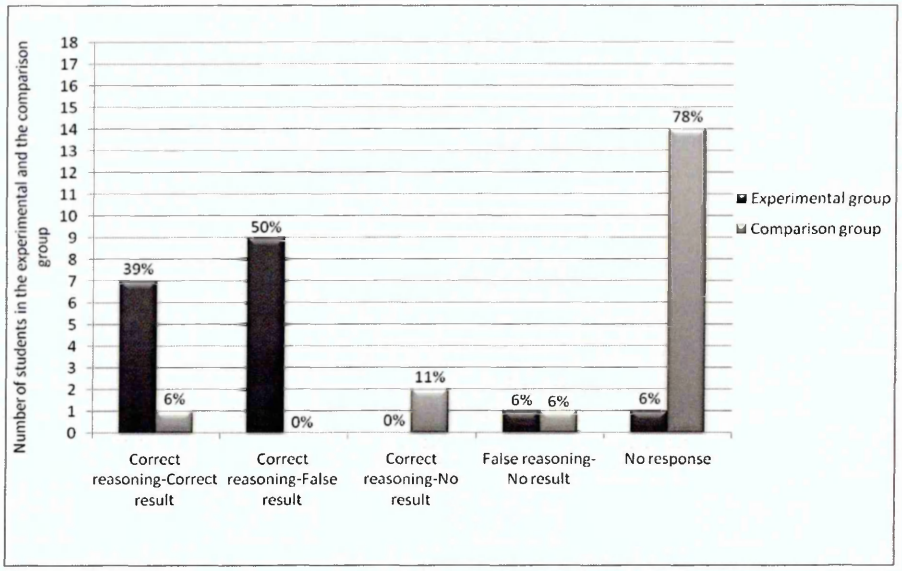


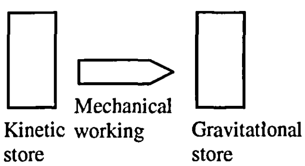
Figure 5.51: Number of students who used correctly/incorrectly the conservation of mechanical store theorem.

The bar chart clearly shows that the great majority of the experimental group students, that is sixteen students, and only three students in the comparison group used the conservation of mechanical store theorem to calculate the initial speed of the coin. Also, the great majority of the comparison students did not respond to the question. These results suggest a good understanding of the conservation aspect of energy among the experimental group students and little understanding among those of comparison group. In addition, they suggest an ability in transferring the acquired knowledge on the conservation aspect of energy and apply it quantitatively for this system. Furthermore, seven students in the experimental group and only one in the comparison group performed correctly the mathematical calculations and ended to a correct value for the initial speed of the coin.

Sub-question 2e: *George throws the coin upwards giving it the initial speed needed to reach the height of 5m and John measures the height. Surprisingly, they see that the coin reached only a height of 4.90m and not at 5m. George repeats the throw of the coin and John measures the height it reaches and its again 4.90m.*

Explain why that happens in terms of energy. Use words or any other way in your explanation.

Six coding categories were identified which are shown in Table 5.62.

Table 5.62: Categories of responses formulating an energy description of the event of the second image.			
Category number	**Category description**	**Experimental group**	**Comparison group**
		Freq.	**Freq.**
1	**It is not reached at 5m height because the amount of energy stored in the kinetic store is transferred not only to the gravitational but also to the internal store.** *'The coin reaches the 4.90m and not the 5m because some of the energy in the kinetic store of the coin is transferred also to the internal store of the air.'*	10/18	0/18
2	**It is not reached at 5m height because an amount of the energy of the coin is lost/consumed.** *'The coin do not reaches the 5m but the 4.90m because when it moves upwards it looses energy and it can't reach the 5m.'*	2/18	1/18
3	**The energy in the chemical store is transferred along a mechanical working pathway to the gravitational store.** '  ' 	5/18	0/18
4	**It is not reached at 5m height because the initial potential energy and so the kinetic energy might be less. Thus, the coin covered less distance.** *'Potential energy should be less at the beginning and then kinetic energy was less and thus it* (the coin) *covered less distance.'*	0/18	2/18
5	**It is not reached at 5m height because of air resistance.** *'Because of air resistance.'*	0/18	1/18
6	**No response.**	1/18	14/18

In the following, coding categories shown in Table 5.62 are further examined with respect to the students' understanding of the degradation aspect of energy. The results of this kind of classification are shown in Table 5.63.

Table 5.6 3: Students' views about the degradation of the energy of the system of the second image.					
Category number	**Category description**	**Experimental group**		**Comparison group**	
		Freq.	**Freq. perc. %**	**Freq.**	**Freq. perc. %**
1	**Energy is degraded.**	10/18	56	0/18	0
2	**Energy is not degraded.**	7/18	38	4/18	22
3	**No response.**	1/18	6	14/18	78

Results shown in Table 5.63 are also shown in the bar chart of Figure 5.52.

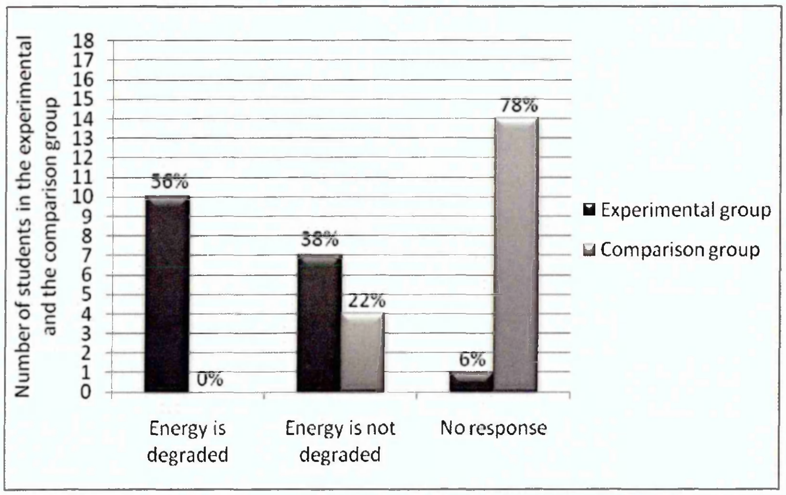


Figure 5.52: Number of students who stated that energy is/is not degraded.

Thus, ten students in the experimental group and none in the comparison group stated that the energy of the system is degraded. These results suggest an understanding of the degradation of energy aspect and an ability in transferring the acquired knowledge in this system among experimental group students whereas no understanding for comparison group students.

Overall, according to the results presented above there is a good understanding of the aspects of the energy store, transfer, conservation and degradation among students in the experimental group and also, a good ability in transferring the acquired knowledge both qualitatively and quantitatively in this system. Regarding the comparison group, results suggested some understanding of the store aspect of energy, a good understanding of the transfer aspect, little understanding of the conservation aspect and no understanding of the degradation aspect for this system.

5.3 COMPARISON OF EXPERIMENTAL GROUP RESULTS REVEALED FROM THE CORRESPONDING QUESTIONS OF POST-TEST'S PART A AND PART B

The analysis carried out in this section focuses upon the investigation of the experimental students' ability in transferring the knowledge on the concept of energy to novel situations. For that reason, results on each of four energy aspects, namely, store, transfer, conservation and degradation, revealed from the study of the system included in post-test's part A, also studied in pre-test's part A, are compared to those revealed from the two novel systems included in post-test's part B. Insights gained by this kind of analysis were considered to contribute to the formulation of an answer to RQ2. Furthermore, findings are also presented in tables and bar charts.

5.3.1 Students' views about an energy store at the beginning of a physical process.

Part A: *Question 2b: At the very BEGINNING of the simulation event, is there any energy? YES or NO? If YES, where? If NO, why not?*

Part B: *Sub-question 1a: Was any energy stored in the system at point A? Answer YES/NO. If YES, name that energy and calculate how much there is.*

Sub-question 2a: As the coin moves up through the air it has kinetic energy. Where does it get this energy from?

Table 5.64: Students' views about the store aspect of energy across all three systems.

Category number	Category description	Part A System 1		Part B System 2		Part B System 3	
		Freq.	Freq. perc. %	Freq.	Freq. perc. %	Freq.	Freq. perc. %
1	There is energy at the beginning- Correct reasoning.	16/18	89	18/18	100	12/18	67
2	There is energy at the beginning- Incorrect reasoning.	2/18	11	0/18	0	2/18	11

Results shown in Table 5.64 are also shown in the bar chart of Figure 5.53.

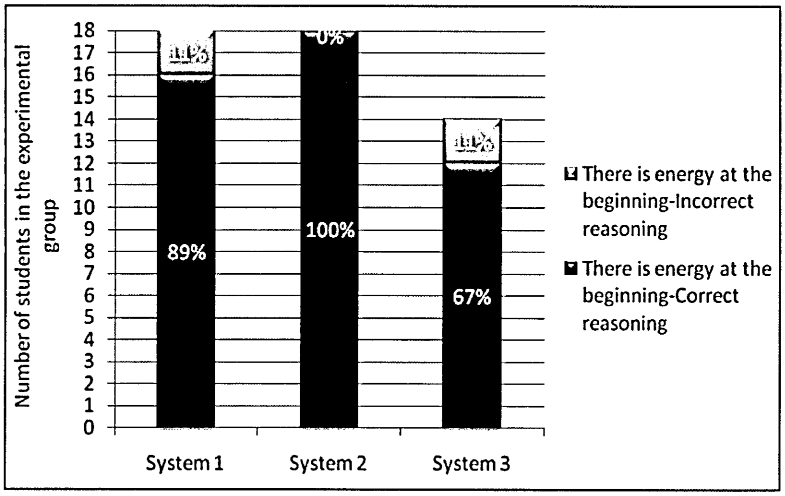


Figure 5.53: Number of students who stated that there is/isn't energy in the system at the beginning of the physical process.

Thus, results for system 1suggest a good understanding of the store energy aspect and those for systems 2 and 3 an ability in transferring this knowledge in different systems. Furthermore, the lower results corresponding to system 3, that is to the coin's throw by the boy, may be interpreted by a difficulty in recognizing the chemical store as the store in which the energy of the system is initially found.

5.3.2 Students' views about an energy store at the end of a physical process.

Part A: *Question 3: Think now about the END of the simulation event, when the ball has stopped moving. Is there any energy? YES or NO? If YES, explain. If NO, why not?*

Part B: *Sub-question 1b: What has happened to that* ***amount*** *of energy at point B? Compare it to that at point A. In what they are similar and in what they differ? Justify your answer.*

Sub-question 2b: At the top of its flight the coin is stationary for a moment. Where is the energy now?

Table 5.65: Students' views about the transfer aspect of energy across all three systems.							
		Part A System 1		**Part B System 2**		**Part B System 3**	
Category number	**Category description**	**Freq.**	**Freq. perc. %**	**Freq.**	**Freq. perc. %**	**Freq.**	**Freq. perc. %**
1	**There is energy at the end-Correct reasoning.**	14/18	78	16/18	89	16/18	89
2	**There is energy at the end-Incorrect reasoning.**	0/18	0	0/18	0	0/18	0

Results shown in Table 5.65 are also shown in the bar chart of Figure 5.54.

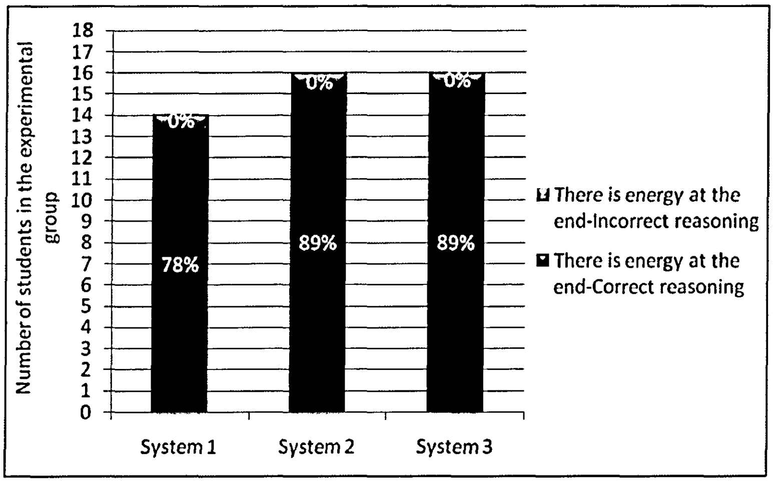


Figure 5.54: Number of students who stated that there is energy in the system at the beginning and justified correctly/incorrectly their response.

Thus, results for system 1 suggest a good understanding of the energy transfer aspect whereas those for systems 2 and 3 an ability in transferring the acquired knowledge in different physical systems.

5.3.3 Students' views about the aspect of energy conservation.

Part A: *Question 4: What can you say about the amount of energy at the BEGINNING compared with the amount of energy at the END?*

Part B: *Sub-question 1b: What has happened to that* ***amount*** *of energy at point B? Compare it to that at point A. In what they are similar and in what they differ? Justify your answer.*

Sub-question 2b: At the top of its flight the coin is stationary for a moment. Where is the energy now?

Sub-question 2d: Taking account of the energy at the 5m height, which you have just calculated: calculate the initial speed of the coin as it leaves George's hand.

Table 5.66: Students' views about the conservation aspect of energy across all three systems.

Category number	Category description	Part A System 1		Part B System 2		Part B System 3	
		Freq.	Freq. perc. %	Freq.	Freq. perc. %	Freq.	Freq. perc. %
1	**Energy is conserved.**	15/18	83	16/18	89	16/18	89
2	**Energy is not conserved.**	3/18	17	2/18	11	0/18	0
3	**No response.**	0/18	0	0/18	0	2/18	11

Results shown in Table 5.67 are also shown in the bar chart of Figure 5.55.

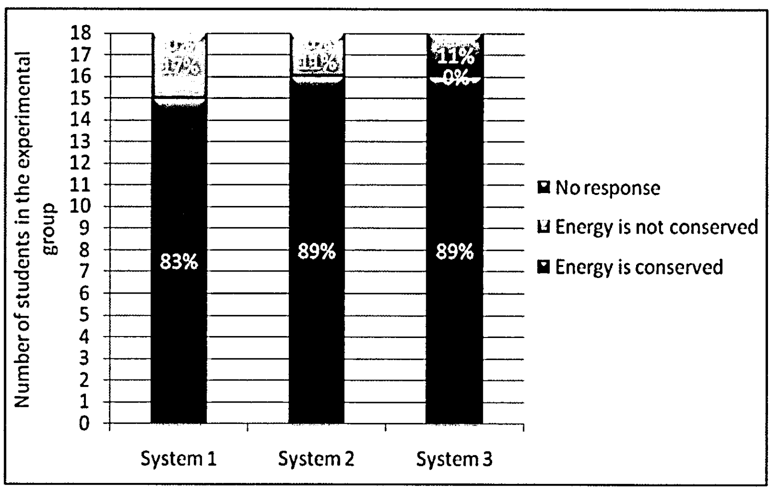


Figure 5.55: Number of students who stated that the energy of the system is/is not conserved.

In the above bar chart, results for system 1 suggest that there is a good understanding of the conservation of energy aspect and for systems 2 and 3 that students in the experimental group were able to transfer the acquired knowledge in other physical systems.

5.3.4 Students' views about the aspect of energy degradation.

Part A: *Question 5: Finally, describe overall what has happened to the energy of the event from BEGINNING to END.*

Part B: *Sub-question 1c: Describe in words or in any other way and in much detail as you can, what has happened to the energy of the system from point A to point B.*

Sub-question 2e: George throws the coin upwards giving it the initial speed needed to reach the height of 5m and John measures the height. Surprisingly, they see that the coin reached only a height of 4.90m and not at 5m. George repeats the throw of the coin and John measures the height it reaches and its again 4.90m.

Explain why that happens in terms of energy. Use words or any other way in your explanation.

Table 5.67: Students' views about the degradation aspect of energy across all three systems.

Category number	Category description	Part A System 1		Part B System 2		Part B System 3	
		Freq.	Freq. perc. %	Freq.	Freq. perc. %	Freq.	Freq. perc. %
1	**Energy is degraded.**	12/18	67	12/18	67	10/18	56
2	**Energy is not degraded.**	6/18	33	5/18	27	7/18	38
4	**No response.**	0/18	0	1/18	6	1/18	6

Results shown in Table 5.67 are also shown in the bar chart of Figure 5.56.

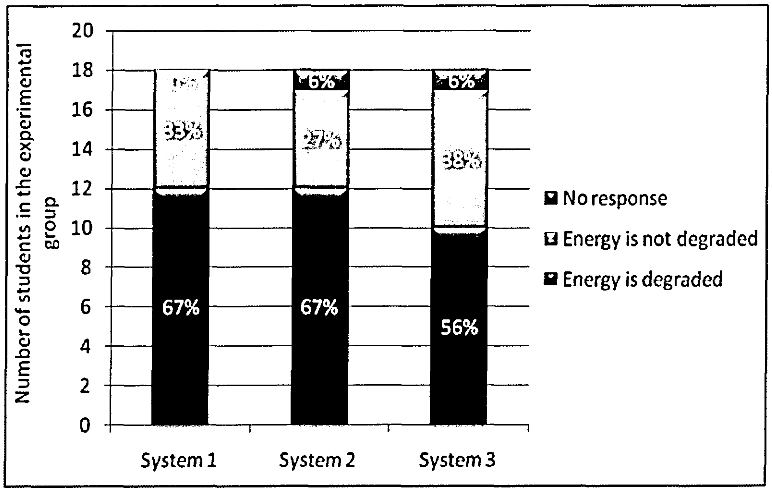


Figure 5.56: Number of students who stated that the energy of the system is/is not degraded.

Results for system 1 suggest a good understanding of the degradation aspect of energy and those for systems 2 and 3 that students in the experimental group were able to transfer this knowledge to different physical systems.

5.4 SUMMARY-DISCUSSION

In sections 5.1.1-5.1.7, the results from analysis of pre-test data were studied and then discussed both for the total number of the participant students and for the experimental and the comparison group in comparison to each other.

Regarding the results revealed from pre-test part A, the main interest was focused on two aspects: the different kinds of interpretations the students formulated for the event of the simulation and; their views on each of four ideas related to the energy concept. Turning to the results revealed from pre-test part B, the main interest was focused on the different initial 'alternative' ideas held by students.

This kind of discussion aimed to extract those findings which would satisfy all purposes of the first research question, as these were defined in Chapter 3-Research Methodology and restated in section 5.1. In reviewing the findings from both part A and B, it is possible to generalize about the students' initial understanding in the following way:

From part A it is suggested that only a very small number of the participant students used energy in their interpretations for the event of the simulation whereas the great majority formulated a force-based one. This kind of findings suggest initial ideas within the 'activity' model, presented and discussed in detail in section 2.3 according to which, 'energy' is associated/confused/used as synonymous of 'force'. Furthermore, concerning the four aspects of the energy concept analysis suggested that: (i) there was some understanding of the energy store aspect, (ii) there wasn't an understanding of the energy transfer aspect, (iii) there was a very weak understanding of the conservation of energy aspect and, (iv) there wasn't an understanding of the degradation of energy aspect among the participant students.

Findings of both the comparative percentage representation and the statistical study with the use of the Fisher's Exact Test of the experimental and the comparison group results suggest no difference between the two groups: (i) in the number of students who formulated an energy-based interpretation of the event of the simulation and, (ii) in the students' understanding on each of the four aspects of the energy concept. This kind of findings clearly suggests that the experimental and the comparison group were initially equivalent in terms of knowledge of the energy concept.

From part B, findings suggest that students in both the experimental and the comparison group expressed ideas on energy which are classified in the same alternative energy models. Specifically, the most frequently used is the 'activity' model according to which, 'energy' is not only associated with 'force' but also with 'movement' and 'activity' (section 2.3). Other most frequently used 'everyday' models are those of the 'depository' and the 'anthropocentric' model respectively. The 'depository' model is presented and discussed in detail in section 2.2 and within this, energy is considered as a causal agent which is stored in certain objects. The 'anthropocentric' model is presented and discussed in section 2.1 and within this, energy is associated with animate objects and in particular with human beings. Furthermore, the comparative percentage representation of the results of the experimental and the comparison group suggested that each of the most frequently used alternative models appear in about the same frequency among students in the two groups. This kind of findings strengthens those suggested from part A that the experimental and the comparison group were initially equivalent in terms of energy knowledge.

The findings summarized above seem to clearly suggest that overall there was little understanding of the energy concept among the participant students prior to formal instruction. Also, they suggest that students participated in both groups expressed ideas on energy which are classified within the same alternative frameworks. These findings could be fully justified by the fact that the classes which participated as the experimental and the comparison group respectively were intact mixed ability classes; rather, it could be argued that a similar degree of understanding the energy concept prior to formal instruction was a desired prerequisite and a kind of an expected result.

Thus, the answer to the first research question is: The conceptions about the concept of energy of a Cypriot cohort of upper high school students prior to teaching were not within the current scientific beliefs; rather, these were similar to a few reported in the International Science Education Literature.

Turning to sections 5.2.1-5.3.4, the results from analysis of post-test data were studied and analyzed. For the results revealed from post-test part A, the main focus was centered on both the students' performance in formulating an energy description of the event of the simulation and on their ideas on each of four energy aspects after instruction.

Regarding the results revealed from post-test part B, the main focus was centered on two aspects: the students' ability in using the energy ideas taught in two novel physical systems and; the extent of the experimental group students' ability in transferring the acquired knowledge on each of four energy aspects in all three different physical systems comprised in part A and B respectively.

The kind of discussion described above aimed to draw those findings which would satisfy both purposes of the second research question, as these were defined in Chapter 3-Research Methodology and restated in section 5.2. In reviewing the findings from both part A and B, it is possible to generalize about the students' understanding after instruction in the following way:

From part A it is suggested that the great majority of the experimental group students formulated a full or a partially full energy description of the event of the simulation whereas only a small number of comparison group students formulated a partially full one. Concerning the store, transfer, conservation and degradation aspects of the energy concept, findings of the comparative percentage representation and the Fisher' Exact Test suggest a significantly greater understanding among experimental group students compared to that of comparison group students. Furthermore, comparison of pre and post-instructional stage results suggest a better improvement in the experimental group students': (i) performance in describing in terms of energy the event of the simulation and, (ii) in understanding each of four energy aspects, compared to that of comparison group students.

From part B, findings revealed from each of the two novel physical systems suggest a good understanding of the energy ideas taught whereas for comparison group students demonstrated little understanding. In addition, experimental group students showed a good ability in using the energy ideas both qualitatively and quantitatively in these systems whereas for comparison group students, this ability seemed to be limited.

Turning to the findings of comparison of the experimental group students' results of all three physical systems comprised in the post-test on each of four energy aspects, they suggest a good understanding and an equally good ability in transferring the acquired knowledge. However, it should be noted that understanding of the degradation aspect seems to be a little lower compared to that of the other three energy aspects. This could be interpreted by the fact that degradation might be considered as the most difficult in terms of the students' understanding of all energy ideas (see, for example: Duit, 1984).

The findings summarized above seem to clearly suggest that overall students in the experimental group acquired a good understanding of the energy ideas after instruction through the research-informed approach whereas little understanding for students in the comparison group followed 'normal teaching'.

Thus, the answer to the second research question is: The conceptions and learning of the sub-cohort of Cypriot students taught through the research-informed approach were significantly higher after instruction compared with those following 'normal teaching'.

Therefore, the proposed-research-informed approach for teaching the energy concept was found to be effective.

CHAPTER 6-EVALUATION OF THE TEACHING: FINDINGS FOR RQ3

In previous chapter, findings from the analysis of pre and post-test data were studied to evaluate the effectiveness of the research-informed teaching sequence in promoting conceptual understanding of the concept of energy.

Evaluation of the teaching through the research-informed sequence continues and concludes in this chapter. In particular, findings revealed from analysis of the case studies of four experimental students are presented and discussed. Based upon them, an answer is formulated to the third research question:

RQ3: How do the understandings of the energy concept, of a small sub-group of students, develop during the lessons of the research-informed approach?

6.0 INTRODUCTION

In the first part of this chapter, the case studies of four students participating in the experimental group are examined. This is followed by a second part in which the experimental teacher's responses to the experimental teaching are discussed in a thematic presentation. The chapter concludes with a summary of the key findings revealed through the study of the first part and the formulation of an answer to the third research question. Discussion of the teacher's responses is continued in the next chapter.

I. CASE STUDY

The case studies of four experimental students who volunteered to be interviewed are examined. The case studies follow two main directions: the students' understanding of the energy concept and their attitudes towards this 'new approach'. These aimed to provide an insight into the experimental group students' developing understanding of the energy concept, addressing the third research question:

RQ3: How do the understandings of the energy concept, of a small sub-group of students, develop during the lessons of the research-informed approach?

As stated in Chapter 3, this question aimed to provide qualitative, detailed insights to illuminate the `findings revealed through the answer to RQ2.

The students' developing understanding of the energy concept is examined and discussed in the light of a longitudinal study which includes background information about their energy learning trajectory. As discussed in section 3.5.1.1, the study of each student's developing understanding of the concept of energy through the research-informed teaching sequence is defined as the student's energy learning profile. Furthermore, each student's case was contextualized with data from the experimental group teacher, the researcher's observations and informal discussions with the four students and from the experimental instruments used.

The data collection research instruments used in this study and the provided model responses to each question are illustrated in Appendixes G, H, I, K, L, M and N respectively.

STUDENT 1: Nicolas

6.1.1 BACKGROUND

Nicolas is an intelligent high achieving student with his academic interests focused on science subjects. He attends afternoon classes in a Private Institute with expertise in preparing students in GCSE English Language and Science Modules. Due to GCSE afternoon classes in Physics, he was the only student in the experimental group who had a previous knowledge of the energy concept which was in accordance to the traditional 'forms' of energy perspective.

Nicolas was among the few students who expressed some objections, to the teacher during lessons, concerning the innovative instructional material on energy at the start of the teaching sequence. One of his objections was that the content of the lessons and the handouts were too theoretical and rather extensive and the exercises in the worksheets only qualitative ones. What he and the rest of the students of the experimental group was used to, was to memorize definitions and the mathematical formulae of physical quantities or physics laws. As was explained to him, the structure and the content of the innovative material aims to offer to the learners an integrated and scientifically consistent knowledge on energy, to the extent their age permits.

A second objection raised by Nicolas at the start of the teaching sequence concerned the different consideration of the energy concept, compared with his previous knowledge, and the new terminology of the energy stores and the energy transfer pathways used. He seemed to be rather unconvinced about the scientific consistency of the proposed energy model and also seemed stressed at one point, probably due to his 'forms' of energy knowledge. However, all Nicolas's objections and mistrust were surpassed as the teaching sequence was proceeding and all became meaningful to him.

In the following, Nicolas's energy learning profile is presented with a commentary.

6.1.2 ENERGY LEARNING PROFILE

The energy learning profile was developed with data from the pre-test, diagnostic probes, interviews and post-test.

Pre-test

Nicolas was the only student in the experimental group who used energy in his interpretation of the event of the simulation (spring-ball system) prior to the experimental intervention. Probably due to his GCSE physics classes, his interpretation of the event of the simulation was partially formulated in terms of the 'forms' of energy terminology, along with some force ideas. His response was as follows:

> *'The end of the spring gives kinetic energy to the ball. The ball starts to move and because of friction it stops after a while. Springs have a property to return to their natural length, provided that their limit is not surpassed because then they are destroyed.'*

Nicolas's responses to the questions on whether there was energy in the system at the beginning and where were as follows:

> *'YES.'*
> *'In the compressed spring.'*

The above responses suggest some understanding of the spring as an 'energy store' and that energy was initially found in the compressed spring.
In addition, his responses on whether there was energy at the end and how this amount is compared to the amount of energy at the beginning, suggested some understanding of

the conservation and degradation of energy aspects respectively. His responses were as follows:

> *'YES.'*
>
> *'Heat energy due to friction between the ball and the ground.'*

and

> *'They are the same.'*

Furthermore, concerning the last question of the pre-test, Nicolas was the only student who formulated an energy description of the event of the simulation. His response was as follows:

> *'At the beginning energy was in the spring. That gave it to the ball (kinetic) and hence because of friction it was converted to heat energy, whereas the ball stopped moving.'*

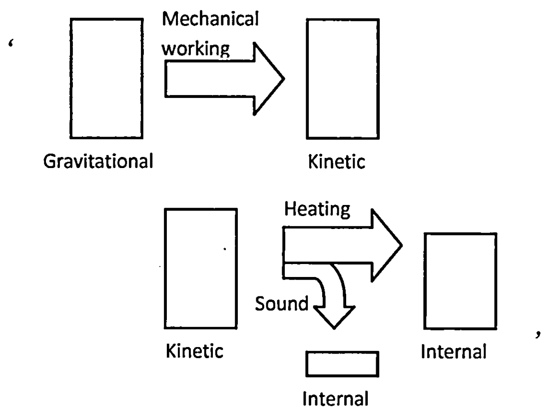
Within the 'forms' of energy theoretical framework, this energy description is almost fully correct since a possible correct response might be as follows: At the beginning, the energy was in the spring in the form of elastic. Hence, it was transferred by mechanical work and converted to kinetic of the ball. As the ball stopped, the energy was converted to heat of the ball and the environment.

First short-length diagnostic probe

On the first short-length diagnostic probe (skier down the slope system), Nicolas gave responses to all questions some of which were in accordance with the ideas and terminology of 'forms' of energy and some with the 'new approach'. In spite of his previous knowledge of the energy concept, the student seemed to adjust to the new scientific context and terminology. This is apparent from both his verbal and diagrammatic energy descriptions, which were as follows:

> *'At distance AB he accelerates at the slope and then he moves with a constant speed until point B. During his downward movement Gravitational store→Kinetic. As soon as he reaches point B kinetic store starts to disappear since it is transferred to the internal along a heating and a sound pathway until he stops.'*

and



Although the student was reluctant to say more than a few sentences, what he did say indicates a good understanding of this system in terms of the 'new approach'.

In the following question concerning the conservation of the energy of this system, the student responded as follows:

> *'I DISAGREE. Energy does not disappear, it only changes form.'*

The student's response suggests an understanding of the conservation of energy aspect expressed however in the 'forms' terminology.

The last two questions sought to probe understanding of the degradation aspect of energy. On the question what would happen to the skier if distance BC was smooth, the student responded as follows:

> *'He would not stop.'*

whereas his response on the question to describe in terms of energy the above statement was as follows:

> *'He would not lose his kinetic and he would keep moving since this* (the kinetic energy) *would not be converted to other forms'.*

Although the student's responses were very brief and the second one formulated in the 'forms' terminology, they suggest an understanding on the degradation aspect of energy.

Nicolas's responses to some parts of this diagnostic probe indicate a shift from the 'old, forms' to the ideas and the terminology of the 'new approach' compared to the pre-test. However it seems that at this point, there is a mixed model with reference to 'forms' in some responses and to the 'new approach' in some others.

First interview

The first question in the interview (metallic rail-marble system) aimed to reveal the student understands of the degradation aspect. According to the physical description given by the researcher to the student, as the ball rolls on the metallic rail some of the energy which was in the gravitational store of the system ball-Earth at the beginning of the process is transferred to the internal store of the ball, the metallic rail and the surrounding air along a heating and a sound pathway. Thus, the ball will reach the lower point D:

> *I:* Ok. Well, tell me why do you think that it will reach point D?
>
> *R:* Because not all energy will be converted from gravitational to kinetic but some will be lost as sound and as heat when it will collide with the air molecules and because of friction.

In a further probing at another point of the interview, the interviewer asked the student what would happen to the ball if it would be let to move for some time. Then, Nicolas explained that the ball will roll up to point D and then oscillate backwards and forwards before coming to rest:

> *I:* Where do you think it would stop?
>
> *R:* Between B and C.
>
> *I:* Ok. Well, when the marble is at BC, do you think that there is energy?
>
> *R:* Yes.
>
> *I:* Ok, you say that there is. Why is there energy?
>
> *R:* To the internal store of the air.

…………………

I: Mm. Tell me, the fact that energy … you told me that energy is stored to the internal store of the air.

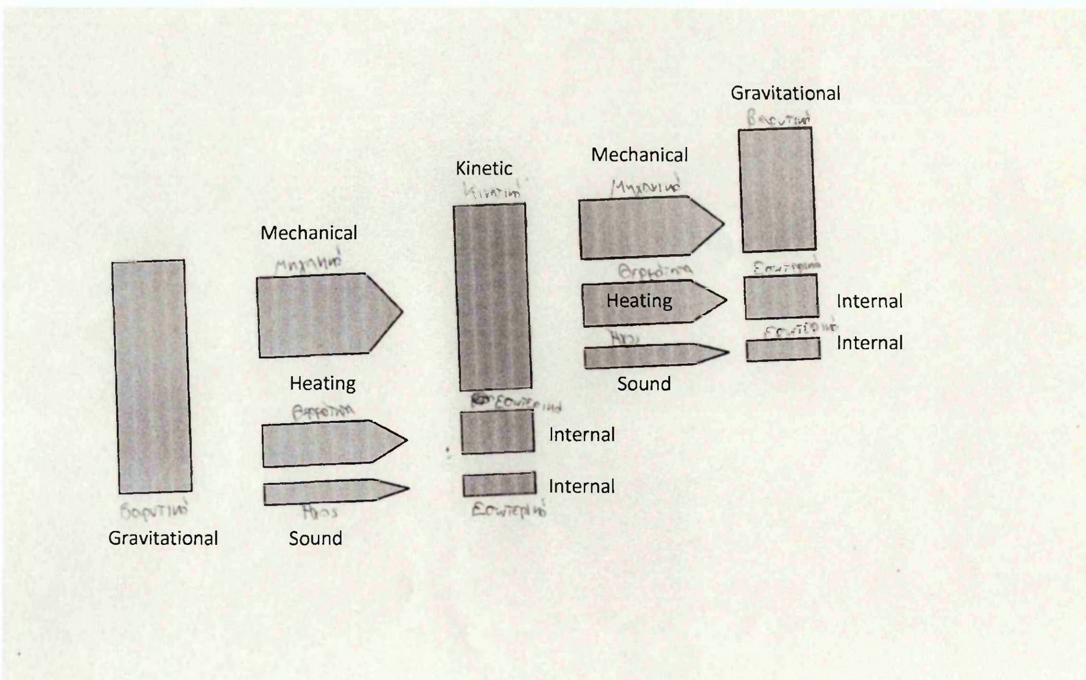
R: Yes.

I: Well, did you learn a specific term in that case, for energy?

R: Degradation of energy.

Taken together these responses indicate Nicolas's understanding of both conservation and degradation concepts although there is evidence of a mixed model in reference to forms of energy and the new terminology.

The student then chose the correct diagram for this system (see, Appendix E) and completed correctly the corresponding energy stores and transfer pathways. The response and the Full Sequence Energy Diagram completed by the student were as follows:



The student was then asked about his understanding of energy stores and transfer pathways:

I: The energy stores and, what an energy store means, what do you understand of them? What is an energy store?

R: It is the energy which is stored in it. It depends on the kind.

……………

I: Ok, on the other hand, what the arrows represent?

R: The ways of energy transfer.

Nicolas was then questioned about the conservation of energy aspect of the system:

I: Tell me, looking at the diagram. If I would ask you to compare the initial energy with the energy at the end, what could you possibly tell me?

R: That they are the same.

I: That is energy …?

R: Cannot disappear.

Nicolas's responses concerning the nature of the energy concept and its role in science were interesting:

I: Tell me Nicolas, energy stores and pathways along which energy is transferred do they exist?

R: Yes.

I: Are these real?

R: Yes.

I: Energy exists, is energy something real?

R: Yes.

The responses were made confidently by the student and suggest that at this point, he had a materialistic view of energy rather than an understanding on the abstract nature of the energy concept.

Furthermore, regarding the role of the energy concept in science, the student did not seem to acquire an understanding on its interpretative role proposed in the theoretical framework of this study, rather he seemed to view energy from an explanatory perspective of the physical world.

I: Why do we use energy stores and pathways in physics?

R: To understand it.

I: Meaning? To understand …?

> *R:* To understand, because they explain correctly all these which take place.
>
> *I:* Meaning?
>
> *R:* The reason … lets say, they explain why the marble will reach point D.

In spite of the fact that the above parts of this interview suggest an understanding of the four aspects of the energy concept introduced in the 'new approach', there is further evidence for Nicolas using a mixed model of energy.

Second short-length diagnostic probe

The first two questions of the second diagnostic probe (worker-box system) concerned the ideas that the amount of energy being transferred along a mechanical working pathway and the amount of energy in the gravitational store of the system object-Earth do not depend on the pathway followed by the object but only on the vertical distance between its initial and final position. Nicolas's responses on the questions were as follows:

> *'Mechanical working done is the same for all 3 cases, because the gravitational energy of the box is the same at the end. I disagree.'*

and

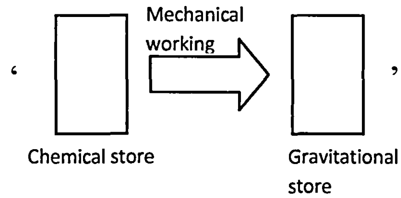
> *'I disagree. It is the same in all cases because h is the same. Egr=mgh.'*

Although the student's responses were brief, they indicate an understanding of both ideas.

In the next two questions, Nicolas interpreted correctly in terms of energy the physical process of the system of the image both verbally and diagrammatically, using a Sankey diagram as requested. His actual responses were as follows:

> *'The energy in the chemical store of the worker is transferred to the kinetic and at the end to the gravitational.'*

and



Finally, the last question of the diagnostic probe was targeting the student's understanding of the conservation and the degradation of energy of this system. According to the physical description of the system, the worker lifts the box up to the first floor by pushing it on a smooth inclined plane. Thus, a possible correct response would be that the amount of energy in the chemical store of the worker at the beginning of the process is the same as that in the gravitational store of the system box-Earth at the end since energy is conserved and furthermore, because the inclined plane is smooth and no energy is transferred along a heating pathway to the internal store of the box, the inclined plane and the surrounding air. The student's response was as follows:

> *'I disagree. Since there is no friction, the chemical energy is converted to kinetic and then to gravitational, the initial amount of energy is the same as the final. If there was friction, the energy of the system would be less, but it won't disappear, simply it would be internal of the air.'*

The above response suggests an understanding of both the conservation and degradation aspects of energy. However it should be remarked that, not all the places in which the energy in the internal store are specified.

Nicolas's responses on the questions of this diagnostic probe indicate a further understanding of the ideas introduced. In the first probe and interview respectively, ability in describing verbally in terms of energy a physical process and in representing it using a Full Sequence Energy Diagram was demonstrated; here, an ability in verbally describing and in representing using a Sankey diagram was also demonstrated. However, the student's responses provide once again some evidence of a mixed model including forms of energy ideas.

Second interview

Nicolas was first asked to interpret verbally and diagrammatically the golf player-ball system. His responses were as follows:

I: Well, could you make a full description of the process in terms of energy? ....

R: Yes.

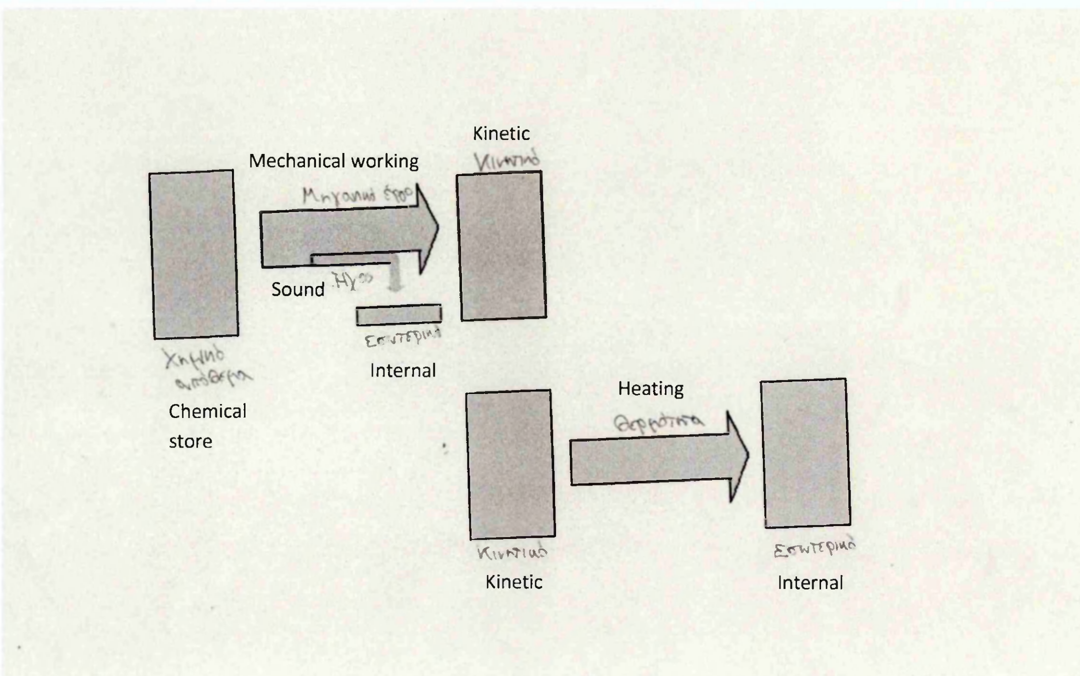
I: Fine. Then make an energy description of the process.

R: The energy of the chemical of the man is stored in the kinetic of the ball and to the internal of the air.

I: Ok, tell me how has it been transferred?

R: From chemical to kinetic along mechanical working and from the kinetic to the internal along heating.

From the above part it seems that there is a change of approach by the student away from forms and a further adjustment to the ideas and terminology introduced. In the following, the student was asked to choose and complete the appropriate Full Sequence Energy Diagram for this system:



Then the student was asked about the conservation of the energy of the system. His response suggests an understanding of the conservation of energy aspect and was as follows:

I: Ok, tell me now, if I would tell you to compare energy at the different stages of the process which takes place in that physical system, what would you tell me?

R: That it is the same.

I: Ok, that is?

R: Energy does not disappear, it simply changes store.

Furthermore, his response to the next question also reveals an understanding of the degradation energy aspect:

> *I:* Ok. Can energy in the internal store be further used? That is for example, the energy in the chemical store is transferred along a mechanical working pathway to the kinetic store of the moving ball. What about the energy in the internal store?
>
> *R:* The temperature rises up.
>
> *I:* Yes, but can be further used?
>
> *R:* No.
>
> *I:* Do you remember what this process is called?
>
> *R:* Degradation of energy.

Regarding the student's understanding of the nature and the role of the energy concept in science, Nicolas's actual response was as follows:

> *I:* Fine. Tell me now, is energy something which exists?
>
> *R:* No, it does not exist, we simply use it to understand better things, the phenomena.

Comparing the above response with the corresponding in the first interview it seems that there is development in the student's understanding at this point, since the view that energy is an abstract idea which is used in interpreting the physical world is expressed.

Post-test

Nicolas responded to all the post-test's part A and part B questions. In order to present the extent of the student's understanding his responses on some of the key questions of part A of the post-test, the corresponding of which were also presented and discussed for pre-test, are examined below.

One of the responses on which an interest might be focused is his interpretation for the event of the simulation (spring-ball system). This was as follows:

> *'They happen because the spring was compressed by exerting a force.*
> - (The spring) *It acquired an elastic store.*
> - (The energy in the elastic store) *This is transferred to the kinetic store of the ball along a mechanical working pathway.*
> - (The ball) *It stopped because energy was degraded.'*

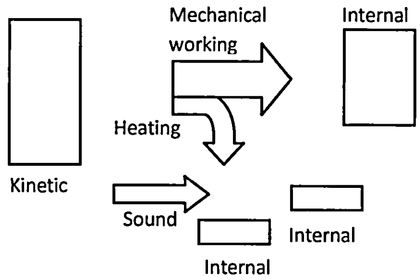
The above interpretation is not formulated in an explicit way since the student uses a kind of shorthand. However, it can be remarked that, whereas the student used energy for the interpretation of some of the changes in the system of the simulation at pre-test and expressed some in terms of 'forms' of energy, then he interpreted every single change and in terms of the 'new approach'.

Another response on which an interest might be focused concerns the student's energy description of the event of the simulation. His response was as follows:

> *'From the elastic store it was transferred to the kinetic (mechanical working) and due to friction with the ground and the air molecules (heating) it is transferred to the internal of the air.'*

Comparing the above response with the corresponding response in the pre-test, it seems that there is a shift in the student's understanding of the energy concept since in his response the pathways along which the energy of the system transferred from one store to another are explicitly referred to. Furthermore, the store in which the energy of the system is finally located is also explicitly referred to. Though, not all three places at which the energy in the internal store can be found are recognized, that is the surrounding air, the ball and the horizontal plane, since only the air is specified.

For the energy description of the system of the stopping car for distance AB in the post-test's part B his response was as follows:



The above diagram suggests that the student considers that there is energy transfer to the internal store not only along the heating pathway but also along a mechanical working pathway. Although the student demonstrated a good understanding of the degradation aspect of energy in the systems included in the data collection instruments it seems that, there is some confusion concerning the energy transfer pathways to the internal store for this system.

Overall description of the energy learning profile

The data set out in the previous sections allow us to sketch out Nicolas's learning profile.

At the start, Nicolas had knowledge of the energy concept which was in accordance with the 'forms' of energy approach. In his interpretation of the event of the simulation, he used his knowledge of energy as well as some force ideas. Furthermore, he formulated an energy description using the 'forms' terminology.

On the questions of the first probe, there was a shift towards the 'new approach' since some of the student's responses were formulated in terms of 'forms' of energy and some in terms of the ideas and the terminology introduced. Moreover, although the student tended to use shorthand, he seemed to be adjusted to the ideas and the terminology of the 'new approach'.

In the first interview following, the student's responses indicated again that there was a mixed model; however, they also revealed an understanding of the energy aspects introduced. On the questions concerning the nature of energy and its role in science, the student expressed views about a materialistic nature and an explanatory role respectively.

On the questions of the second probe, Nicolas formulated once again responses which provided an evidence of a mixed model. Nevertheless, these revealed an understanding of the energy ideas introduced as well as and of secondary energy issues.

Regarding the second interview, there was a change of approach away from the 'forms' of energy since the student's responses were all formulated according to the ideas and the terminology of the 'new approach'. Furthermore, development in the student's understanding was demonstrated concerning the nature and the role of energy in science compared to that in the first interview, since the student expressed views about an abstract nature of energy and an interpretive role in science.

At the end, Nicolas's overall achievement on the post-test's questions revealed a good understanding of the energy ideas introduced in the 'new approach'. Moreover, the student demonstrated the ability in transferring the acquired knowledge in various different systems both qualitatively and quantitatively.

6.1.3 THE STUDENT'S RESPONSE TO THE 'NEW APPROACH'

Apart from his objections, which could be quite justified by the fact that the innovative material was leading him to a new consideration of the energy concept, Nicolas expressed the opinion to the researcher in an informal discussion after the end of the first interview that the use of visual representations to represent the energy stores and transfer pathways, computer simulations and images of systems observed in the real world, made the lessons more exciting and their content more easier to understand.

Nicolas expressed some concerns about the presence of the video camera during the lessons at the start of the teaching sequence. He asked to be seated at a position in the classroom so as not to be within the main frame of the screen. Fortunately, this did not prevent him from being an active learner in all lessons of the teaching sequence. However, when the class was asked for volunteers to be interviewed, Nicolas was among the volunteers, after he was assured that the content of the questions in the interviews would be about physics and not about personal affairs. He furthermore expressed the opinion that interviewing on physics would be an interesting experience for him.

As the teaching sequence was about to end, Nicolas had two informal discussions with the experimental group teacher and the researcher in which he asked some information about the professional prospects of studying physics, apart from becoming a physics teacher.

STUDENT 2: Andria

6.2.1 BACKGROUND

Andria is a student who according to the experimental group teacher report, started at the beginning of the school year as a low achiever and after a constant interest and effort in physics lessons, progressed to a rather middle achiever. She did not seem to have knowledge of the energy concept due to any kind of formal instruction, as in the case of Nicolas, prior to the teaching intervention.

In the following, Andria's energy learning profile is presented with a commentary.

6.2.2 ENERGY LEARNING PROFILE

The energy learning profile was developed with data from the pre-test, diagnostic probes, interviews and post-test.

Pre-test

Andria, as the majority of the students in her class, used force and motion to interpret some of the changes observed in the simulation (spring-ball system) prior to experimental intervention. Her response was as follows:

> *'These events happen because when a compressed spring stretches having an object in front of it, it will push it to move away because it exerts* (the spring) *a force F on it* (the ball) *which changes its state of motion.'*

Her responses to the questions on whether there was energy in the system at the beginning and where, were as follows:

> *'No.'*
> *'There isn't any energy at the beginning of the event because the spring remains compressed and at rest thus the ball also remains at rest because no force is exerted on it or on the spring.'*

The reasoning of the above responses suggests lack of understanding of the spring as an 'energy store' and that energy was initially found in the compressed spring.

Andria's response on the question whether there is energy in the system at the end was based on a similar reasoning:

> *'No.'*
> *'There isn't any energy once the object* (probably the ball) *stops moving because no force is exerted and also it does not participate in any kind of motion so as to have energy that is ΣF is 0.'*

As can be noticed in the above responses, energy is strongly associated with force and motion and also, it seems that there is the notion that there isn't any energy at the beginning and the end because the spring and the ball do not take part to any kind of activity. These, clearly suggest initial ideas within the 'activity' model of energy (Gilbert and Pope, 1986).

Furthermore, the student's response on the conservation of energy aspect is interesting:

> *'The amount of energy at the beginning is the same to the amount of energy at the end.'*

Logically the student is correct-she has stated that there isn't any energy at the beginning or at the end; but this certainly is not evidence for an understanding of both the conservation and the degradation aspects of energy.

Andria's response concerning the last question of the pre-test in formulating an energy description of the event of the simulation seems to justify all the above discussion:

> *'At the beginning there isn't any energy in the object* (probably the ball) *because it is at rest. Hence it acquires energy because it is set up in motion by the force exerted by the spring on the ball and then there isn't any energy because it comes to rest.'*

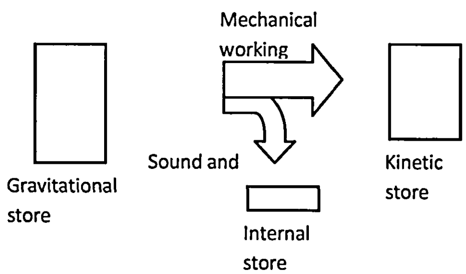
Moreover, in the above energy description it seems that energy is viewed as something which is not conserved, rather as a short-term product which is generated, is active and then disappears or fades. These views suggest initial ideas which strongly refer to the 'product' framework of energy (Gilbert and Pope, 1986).

First short-length diagnostic probe

On the first two questions of the short-length diagnostic probe, concerning the verbal and diagrammatic energy descriptions of the system (skier on the slope), Andria responded as follows:

> *'At the beginning at point A there is a gravitational store which is transmitted along a mechanical working pathway to the kinetic store and along sound to the internal store at the end.'*

and



The above verbal description is almost a full and correct one except the fact that heating pathway is not specified; however, this is specified in the diagrammatic description.

Concerning the diagrammatic description, although the energy stores and transfer pathways are specified correctly, they were used in a way which suggests a difficulty in representing the energy transfer process within a system. This might arise from a difficulty in recognizing the different situations of a physical process; in the system under study, a two-step process takes place, corresponding to distances AB and BC respectively, whereas it is represented as one-step situation by the student.

Andria's response on the following question concerning the conservation of the energy of the system was as follows:

'I agree because in my opinion the amount of energy at points A-B is greater because the surface is smooth and inclined whereas at points B-C is less because his speed is reduced and the surface is not smooth as at A-B.'

This kind of response is incorrect and suggests that there isn't an understanding of either the conservation or the degradation energy aspects. Furthermore, this consists a phenomenological response since it is justified through a reasoning in which only the characteristics of certain parts of the system were taken into consideration, that is, the kind and the shape of the surfaces at distances AB and BC respectively. According to Papadouris, Constantinou and Kyratsi (2008), phenomenologically oriented responses are defined as those in which the observed changes 'were confined to the physical entities of the system under study and failed to make connections to relevant concepts or other theoretical constructs'.

The next two questions were targeting the student's understanding of the degradation aspect of energy. On the question what would happen to the skier if distance BC was smooth, the student responded as follows:

'If distance BC was smooth then the skier would move faster than if the surface would not smooth.'

In the above response, the main focus was placed by the student on the different speed with which the skier would move in the two different physical situations rather than on the fact that the skier would move with constant speed and would not stop at point C. This suggests lack of understanding of the degradation aspect of energy.

Turning to the second question to interpret in terms of energy the description made above, the student's response was as follows:

'At the beginning there is a gravitational store in the skier at points AB then the energy is transmitted along a mechanical working pathway to the kinetic store and along sound and heating to the internal store but this time the energy in the kinetic store at points B-C is less.'

In this response it seems that the student failed in understanding the question and formulated an energy description of the full process instead of the event at distance BC. However, it suggests a lack of understanding on the degradation aspect of energy since the student referred to an energy transfer to the internal store along a heating pathway, which is reinforced by the student's response to the previous question.

Overall, Andria's responses to the questions of this diagnostic probe suggest some understanding of some of the ideas of the 'new approach' and some improvement in the student's initial knowledge of the energy concept. In particular, they suggest that the student was fully adjusted to the terminology introduced; furthermore, it seems that some understanding of the store and the transfer aspects of energy were acquired at this point whereas not on the conservation and the degradation.

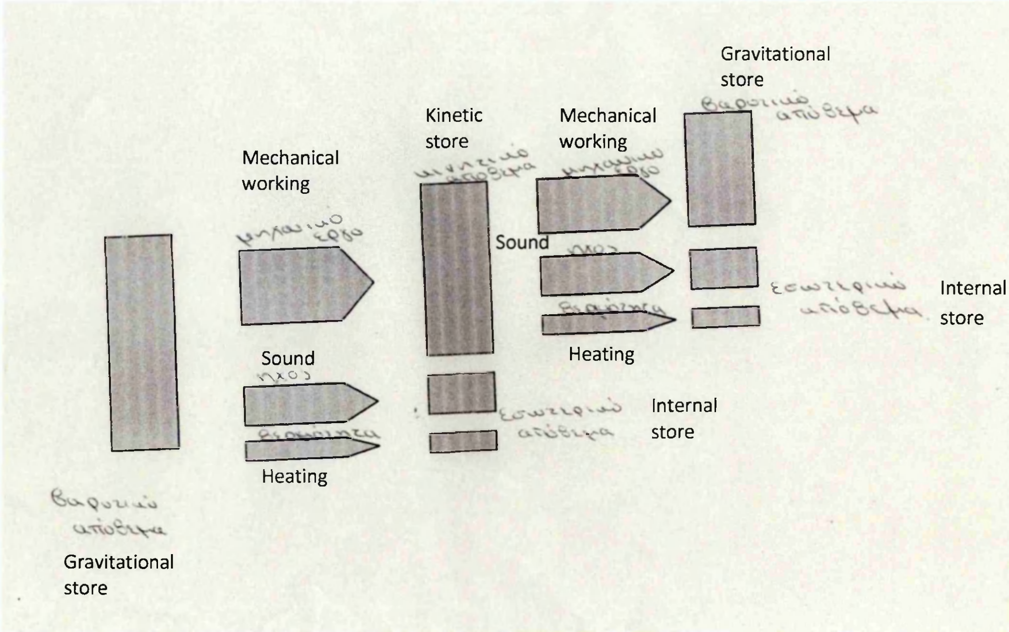
First interview

The first question posed to Andria was at what point the ball would reach on the metallic rail (metallic rail-marble system) after it was let from the highest point A.

> *I:* ……. What do you think about?
> *R:* I claim that, … , will Michael initially push the ball?
> *I:* No, we let it to roll on the metallic rail, ok?
> *R:* I believe that it will reach point D …
> *I:* Mm.
> *R:* … initially from point A to B because it moves downwards and will have acceleration but after the point B acceleration will start to decrease, so it will not reach point E, it will reach up to somewhere lower, up to point D.

Although the student responded correctly, according to the system description made by the interviewer, no energy ideas such as degradation were used in her reasoning whereas she does refer to acceleration. Rather, it seems that her response was an intuitive one, based on 'everyday life' observations.

Andria then chose the correct diagram for this system (see, Appendix E) and completed correctly the corresponding energy stores and transfer pathways. The response and the Full Sequence Energy Diagram completed by the student were as follows:



Although the student completed correctly the energy stores and the transfer pathways on the diagram, she did not seem to be very confident and in addition, there were moments in which some hesitation and confusion was demonstrated. Then, the interviewer helped the student with clarifying questions. One such incident is the following:

> *I:* Mm, there are some rectangles which you didn't name. Don't they represent something?
>
> *R:* The internal store?
>
> *I:* What do you think? What do you think with respect to that system, the ways of transfer you showed to me, what do you think?

The student then asked about her understanding of the energy stores and transfer pathways:

> *I:* Ok, however, what do you understand about energy stores, what are these?
>
> *R:* It is a way of energy transfer.
>
> *I:* It is a way of energy transfer. And what mechanical working, sound and heating are?
>
> *R:* Ways of energy transfer.
>
> *I:* That means that they are the same thing?

R: No. I think that the stores are where energy is, where energy is saved, where energy is stored.

I: Where energy is stored, whereas the arrows are?

R: Ways of energy transfer, lets say, how energy is transferred from one energy store to another.

Although the student seemed to be in some confusion at first, in the following she managed to demonstrate an understanding of the energy stores and transfer pathways. Andria's response concerning the conservation of energy of the system suggests an understanding of the aspect:

I: Now tell me, what do you think about the initial and the final amount of energy?

R: First of all, I think they are the same because energy which was there at the start there is also at the end because energy is transmitted, lets say, if it increases at one, it decreases at another. It is always the same.

Furthermore, the student's response concerning the energy of the system at the end of the physical process again suggests an understanding of the conservation of energy aspect and also of degradation aspect. This was as follows:

I: Ok. Tell me, after the marble stops moving, what happens to the energy?

R: It continues to exist.

I: It continues to exist.

R: In the same amount as initially.

I: Where do you think that energy is stored at the end?

R: In the air, in the environment.

I: In the environment. Do you remember the term for that procedure, that is, when energy is stored in the environment? Do you remember how it is called?

R: I think no.

…………

I: Yes, energy … a particular term is used.

R: It is that where energy cannot be further used. Let me remember. E ....
I don't remember the term.

....

I: And, in what store is the energy which cannot be further used is usually stored?

R: In the internal.

Andria's comments here revealed an understanding of the degradation aspect, even though she couldn't remember the 'label'.

Finally, the student asked about her understanding of the nature and the role of the energy concept in science. Her responses were as follows:

I: ... Ok, now tell me, energy stores and pathways exist?

R: I believe yes because lets say in order to be stores, some objects must be present, materials and, we will see lets say their movement, for example that marble what kind of movement it performs, so we understand what kind of store is.

....

I: Energy exists? Can we perceive it, what do you think energy is?

R: Meaning?

I: Is it something which exist? Is it something materialistic? Is it something abstract? What do you think that energy is?

R: It is something which is found in all objects, lets say a painting hanged on a wall, there is energy in it.

I: Fine, tell me now, why do we use the concept ... the idea of energy stores and that of energy transfer pathways? Why do we use them in physics, for what purpose?

R: To understand lets say how much energy is there ... not exactly how much energy is there, lets say, how to express it ...?

I: Think about it and tell me.

R: How much energy there is in every object, but not exactly how much energy. Lets say, ...

I: Yes, for example to that system, we have used the stores and the transfer pathways. Why did we do that?

R: To understand lets say the kind of movement the objects perform.

The student's responses, although not explicitly expressed, suggest a materialistic view of the energy concept and an explanatory role respectively. Regarding the materialistic view, it is mainly suggested by the statement that: 'It is something which is found in all objects …'. As far as it concerns the explanatory role of energy, it is mainly suggested by the student's statement: 'To understand lets say the kind of movement the objects perform'.

Furthermore, the student's responses to the interview questions suggest a shift in her understanding of the energy ideas compared to those made on the first probe, although the one followed the other, and is focused on the conservation and the degradation aspects of energy. This shift might be attributed to the fact that the first probe was administered just before the Easter holidays whereas the interview was conducted just after, giving thus the chance to a student with a constant effort such as Andria to review the content of the first three lessons.

Second short-length diagnostic probe

On the first two questions of the second diagnostic probe (worker-box system) concerning the amount of energy which is transferred along a mechanical working pathway and the amount of energy in the gravitational store of the system object-Earth, Andria responded as follows:

> *'I disagree because it does not depend on the way followed but it relates to the height. That is in all three cases it* (the box) *will be lifted up to the same height and thus mechanical working is the same in all three cases.'*

and

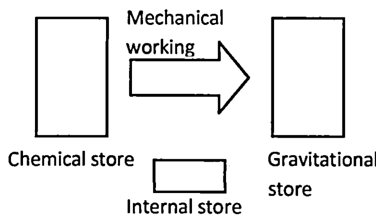
> *'I disagree because in all three cases there will be the same store with the same amount of energy. Thus the amount of energy is the same in all three cases because it does not depend on the way along which the box is lifted up to the first floor.'*

The above responses suggest an understanding on the ideas that both mechanical working done and the amount of energy in the gravitational store does not depend on the pathway followed but only on the vertical distance between the two positions.

Andria's responses on the following two questions, concerning the verbal and the diagrammatic energy description of the physical process in this system were as follows:

> *'At the beginning there is a chemical store which is transmitted along a mechanical working pathway to the internal store and at the end to the gravitational store.'*

and



The above verbal and diagrammatic energy descriptions suggest again a difficulty in recognizing the situations in a system and representing them accordingly in terms of energy. In particular it seems that, the fact that the inclined plane was smooth was not taken into consideration and thus the student specified internal store as another place at which the energy in the chemical store is transferred.

Finally, the student's response on the last question reveals an understanding on the conservation of energy concept:

> *'I disagree. It is the same because the energy is transmitted from one energy store to another and thus it is always the same.'*

Overall, Andria's responses on the questions of this diagnostic probe were either correct or partially correct suggesting thus, a further shift in her understanding of the energy concept.

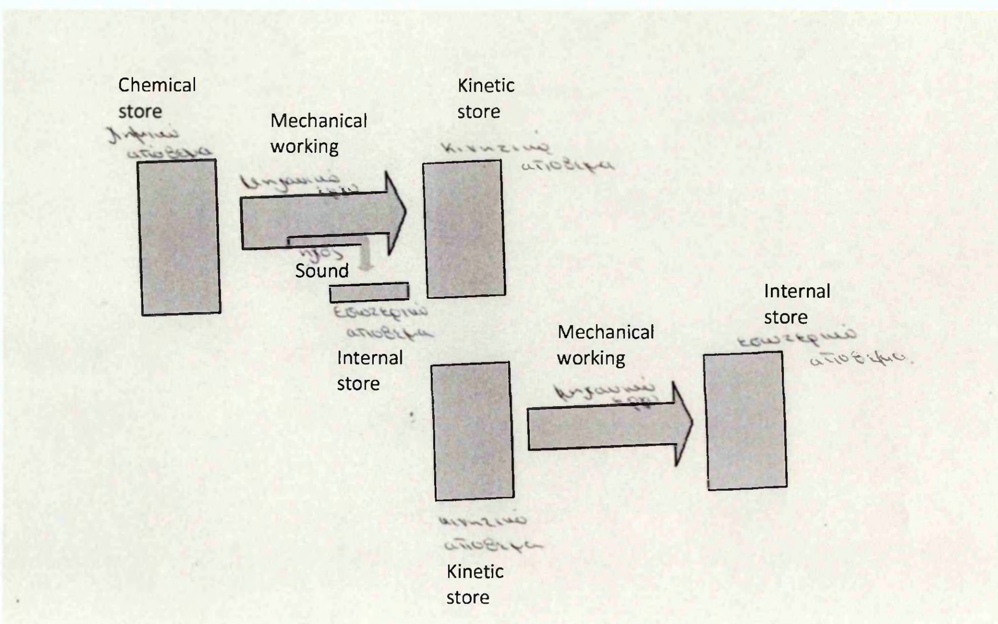
Second interview

At the beginning of the second interview, Andria asked to interpret verbally the physical process in the system (golf player-ball system). Her verbal interpretation was as follows:

> *I:* ... Well, would like to describe this process in terms of energy?
>
> *R:* Mm, well initially energy is stored in the chemical store, hence it is transmitted to the kinetic store along a mechanical working pathway and afterwards, in the end, to the internal store.

Then, the student was asked to choose and complete the appropriate Full Sequence Energy Diagram for this system:

> *I:* According to your energy description, if you would choose between these two energy diagrams, which one do you think would describe best the process?
>
> *R:* I believe the second one because due to the fact that the ball finally stops, it means that energy has been transferred along both a heating and a sound pathway.
>
> *I:* Fine. Take the process from the beginning and write on the diagram which is which.



Both the student's energy interpretation and the diagrammatic representation were correct and were made with much more confidence, compared to those in the first interview and the probes, suggesting thus a further improvement in her ability in describing a process in terms of energy. The student's response on the next question concerning the degradation of the energy of the system was as follows:

> *I:* Ok. Tell now dear Andria, where an internal store can be found?
>
> *R:* In the atmosphere, actually is the energy which cannot be further used.
>
> *I:* Ok. What this process is called in physics?
>
> *R:* Energy is degraded.

The above response reveals an understanding of the degradation aspect of energy and also shows that Andria has learned the 'label' 'degradation'. However, not all the places at which the energy which is degraded are specified; in particular, only the surrounding air is specified whereas the ground and the ball are not. Moreover, her response to the question regarding the conservation of the energy of the system suggests an understanding of the aspect:

> *I:* And if I would tell you to compare the initial to the final energy, what would you tell me?
>
> *R:* Surely initial energy is greater than the final because a part of it has been transferred to the atmosphere, but the total amount of the energy of the system is the same, it does not change.

Finally, her responses on the questions concerning the nature of energy and its role in science were as follows:

> *I:* Now, from all you have learned in this chapter, what do you think that energy is? Why do we use energy in physics? Energy exists or it is something abstract?
>
> *R:* It surely exists in all objects. It is simply used to understand the activity or the movement that an object can perform or it is performing.

The above responses suggest that no change in the student's understanding of the nature of energy and its role in science was made; it seems that the student held the view about a materialistic nature and an explanatory role of energy expressed in the first interview.

Post-test

Andria responded to the post-test's part A and part B questions using the ideas and terminology introduced in the teaching sequence. Her responses on two of the key questions of part A of the post-test, the corresponding of which were also presented and discussed for pre-test, are followed.

The first one concerns her interpretation of the event of the simulation. This was as follows:

> *'At the beginning the energy is in the elastic store and hence it is transmitted along a mechanical working pathway to the kinetic store and then along sound and heating to the internal store.'*

The above response, compared to the corresponding one in the pre-test, suggests a shift in the student's understanding on the energy concept. The student seemed to abandon her initial 'activity' ideas and formulated an interpretation in terms of the energy ideas of the 'new approach'.

The second one concerns the student's energy description of the event of the simulation. Her response was as follows:

> *'At the beginning there was energy in the ball which was transferred along the transfer pathways that is along mechanical working, sound and heating to the other store however its amount of energy at the end was less since it was degraded.'*

Although the student formulated a correct interpretation in terms of energy of the event of the simulation, this does not apply in the case of her energy description. It seems that the above energy description is restricted to the ball's movement, which might be attributed to some kind of confusion. Furthermore, it suggests an understanding of the degradation of energy aspect.

Furthermore, in examining Andria's responses on the post-test part B questions, it seems that the student had no particular difficulty in responding correctly to those in which a qualitative response in terms of energy was required. However, a difficulty was demonstrated in those questions in which a quantitative response was required. In particular, the student responded correctly to those quantitative questions in which a simple substitution of the data on the calculating formula of an energy store was required; in those questions where more complicated reasoning and a more sophisticated mathematical elaboration was needed, the student used erroneous reasoning as in the case of the mechanical working-kinetic store theorem or did not respond as in the case of the conservation of mechanical store theorem.

Overall description of the energy learning profile

At the start, Andria's interpretation of the event of the simulation and her energy description revealed that her initial views on energy were within the 'activity' and the 'product' models.

On the questions of the first probe, some of the student's responses were justified through energy and formulated in terms of the energy ideas of the 'new approach' whereas some others, through a phenomenological reasoning. Furthermore, her energy description of the physical process suggested an understanding of the energy aspects of store and transfer. However, her diagrammatic energy description revealed a difficulty in recognizing the different situations of the physical process and to representing them accordingly in terms of energy. In addition, the student's responses suggested that no understanding was acquired on the conservation and the degradation aspects of energy at this point.

The student's responses on the questions of the first interview, although made with not much confidence and with some hesitation revealed a shift in the student's understanding of the energy ideas. This shift was focused on the conservation and the degradation aspects of energy. The student also expressed views about a materialistic nature of energy and an explanatory role in science.

On the questions of the second probe, Andria's responses were correct or partially correct and formulated in terms of the energy ideas introduced in the 'new approach'. Though, her diagrammatic description suggested again a difficulty in recognizing the situations in a physical process and in representing them accordingly in terms of energy.

Furthermore, the student's responses on the questions of the second interview were made with confidence suggested an understanding of all four aspects of energy. At this point, the student no more demonstrated a difficulty in recognizing the different situations of the physical event or to representing it in terms of energy. However, the student's responses on the questions concerning the nature and the role of energy in science did not seem to change compared to those expressed in the first interview since she expressed once again views about a materialistic nature and an explanatory role.

Finally, Andria's overall achievement on the post-test's questions suggested an improvement in her understanding of the energy concept compared to her initial 'activity' and 'product' views. Although not all of the student's responses were completely correct, they revealed an understanding of the energy ideas and the terminology introduced in the 'new approach' and the ability in transferring it in various different systems. Moreover, a difficulty was demonstrated in transferring the acquired knowledge in solving quantitative energy questions; the student responded correctly on those questions in which a simple substitution of the data on the calculating formula of the amount of energy of an energy store was required. On the questions in which a more sophisticated reasoning and mathematical elaboration was required, as in the cases of the mechanical working-kinetic store theorem and the conservation of mechanical store theorem, the student either used an erroneous reasoning or did not respond to the question.

6.2.3 THE STUDENT'S RESPONSE TO THE 'NEW APPROACH'

Andria was among the students who responded with enthusiasm to the innovative teaching approach of energy from the first lessons of the teaching sequence and seemed to adjust to it quickly. She was an active learner during all lessons of the teaching sequence and seemed to be challenged to do her best. In an informal discussion with the researcher at the end of the first interview, she expressed the opinion that the use of visual representations, images and simulations in which physical processes of the real world were simulated made the lessons more interesting and comprehensive especially for the 'not so talented in physics students', as she commented.

Concerning the presence of the video camera during the lessons of the teaching sequence, the student did not seem to be disturbed at any way. When the class was asked for volunteers to be interviewed, Andria was among those who volunteered.

Furthermore, she seemed to see the interview process as a new and interesting experience.

STUDENT 3: Amalia

6.3.1 BACKGROUND

Amalia is a low achievement student though with a constant interest and effort on physics lessons. As the great majority of her classmates, she did not seem to have acquired any knowledge by formal instruction on the energy concept prior to experimental intervention.

In the following, Amalia's energy learning profile is presented and commented.

6.3.2 ENERGY LEARNING PROFILE

The energy learning profile was developed with data from the pre-test, diagnostic probes and interviews and post-test.

Pre-test

Amalia's interpretation of the event of the simulation (spring-ball system) was force based and was as follows:

> *'This happens because a force is exerted on the spring to be stretched and then the spring exerts a force on the ball.'*

On the questions followed, concerning whether there was energy in the system at the beginning and where, the student responded as follows:

> *'No.'*
>
> *'Because no energy is exerted on the object* (possibly the ball). *The spring is compressed however no energy is exerted on the ball.'*

The above responses suggest that there isn't an understanding of the spring as 'an energy store' and that energy is in the compressed spring. Furthermore, it seems that the word 'energy' is used as synonymous with the word 'force', which again refers to the 'activity' model of energy.

The student's response on the question about the energy of the system at the end was as follows:

> *'No.'*
> *' Because once the spring starts its action the ball acts with it. However, due to the fact that it* (the ball) *stops moving there is no energy.'*

This kind of response suggests that there isn't an understanding of the conservation of energy aspect. Moreover, in the reasoning of this response, energy is associated with motion, which provides a further evidence of initial ideas on energy within the 'activity' model.

Amalia's response concerning the conservation of the energy of this system was interesting:

> *'There is no change in the energy.'*

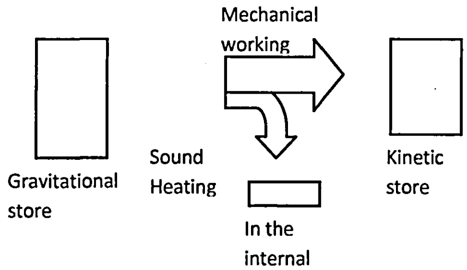
Considering solely the above response it seems that there is an understanding of the conservation aspect of energy. However, the study of this response in relation to the responses on the previous two questions suggests lack of understanding of the conservation of energy aspect.

Finally, the student did not formulate an energy description as was required by the last question.

First short-length diagnostic probe

Amalia responded to the questions of the first probe (skier on the slope system) and her responses regarding the verbal energy description of the system and its diagrammatic representation were as follows:

> *'At point A there is gravitational store which is transmitted along a mechanical working pathway to the internal store along sound and heating and at point B, C kinetic store.'*



In both the above responses, the energy stores and the transfer pathways were specified correctly, which suggest some understanding of these ideas; however, the way with which these were used also suggests confusion on these ideas.

Concerning the verbal description, it seems that this confusion might arise from a difficulty in sequencing the different events which take place in the system resulting in a difficulty in describing them in terms of energy in the right order. Turning to the diagrammatic representation, this confusion might be caused by a difficulty in recognizing the different situations of the physical process, that is, it is about a two step situation corresponding to distances AB and BC respectively. Furthermore, this difficulty might result in the one step energy representation by the student.

The student's response on the next question concerning the conservation of energy of the system was as follows:

> *'I agree because in my opinion the energy at points A-B is transmitted at point BC where the surface is not smooth.'*

The above response suggests lack of understanding of both the conservation and degradation energy aspects.

The last two questions aimed to probe understanding of the degradation aspect of energy. On the question what would happen to the skier if distance BC was smooth, Amalia's response was follows:

> *'He would move faster.'*

Regarding the above response, it provides some evidence that there isn't an understanding of the degradation aspect of energy since the student did not take into account the fact that the amount of energy in the kinetic store would be the same and thus the skier would move at distance BC with constant speed and would not stop at point C.

Furthermore, on the question to interpret in terms of energy the description made above, the student's response was as follows:

> *'At point A there is a gravitational store which is transmitted along a mechanical working, sound and heating pathway to the internal store with kinetic be the biggest store.'*

This kind of response suggests that the student failed to understand the question posed. As could be noticed, the student formulated an energy description of the full process which takes place in the system rather of the event at distance BC. Moreover, it also suggests lack of understanding of the degradation of energy aspect at this point since the student referred to an energy transfer to the internal store along a heating pathway whereas distance AB is smooth.

Overall, Amalia's responses on the questions of this diagnostic probe indicate that she adjusted to the terminology introduced in the 'new approach'. They also suggest that some understanding of some of the energy ideas was acquired by the student and thus some development in her initial understanding of the energy concept. In particular, they suggest that at this point, an understanding of the store and transfer energy aspects was acquired whereas there is little evidence of an understanding of the conservation and the degradation aspects.

First interview

On the first question of the interview (metallic rail-marble system), Amalia chose correctly point D as the point at which the marble would reach on the rail after it is released from point A:

> *I:* … With whom of the two do you agree?
> *R:* Well, the first said A, B, C, …
> *I:* … D whereas Niki A, B, C, E.

R: I think with the first, that it will go from A to B, C and will reach point D because it exerts energy? I mean that the marble has … .

I: Well, so you believe that it will move from A …

R: From A came to D.

I: It came to D. Dear Amalia, why do you believe that?

R: For the reason that … because of the energy which is exerted.

From the above part it seems that, the student's response was an intuitive one, based on everyday observations rather than on an understanding of the degradation aspect of energy. Furthermore, it seems that the word 'energy' was used as synonymous of the word 'force', possibly friction.

The lack of understanding on the degradation aspect of energy is also suggested in the following part:

I: What happens to the energy, is it conserved or lost after the ball stops?

R: I believe that it is conserved somehow but in the store …

I: In which store is it goes, if it is conserved?

R: If it would be in the gravitational it should be at a height …

I: Yes …?

R: … if it was in the kinetic, it is not moving …

I: Yes …?

R: Then energy might be lost at this point somewhere.

I: You think that energy is lost.

R: Since it seems that there isn't any kind of energy store.

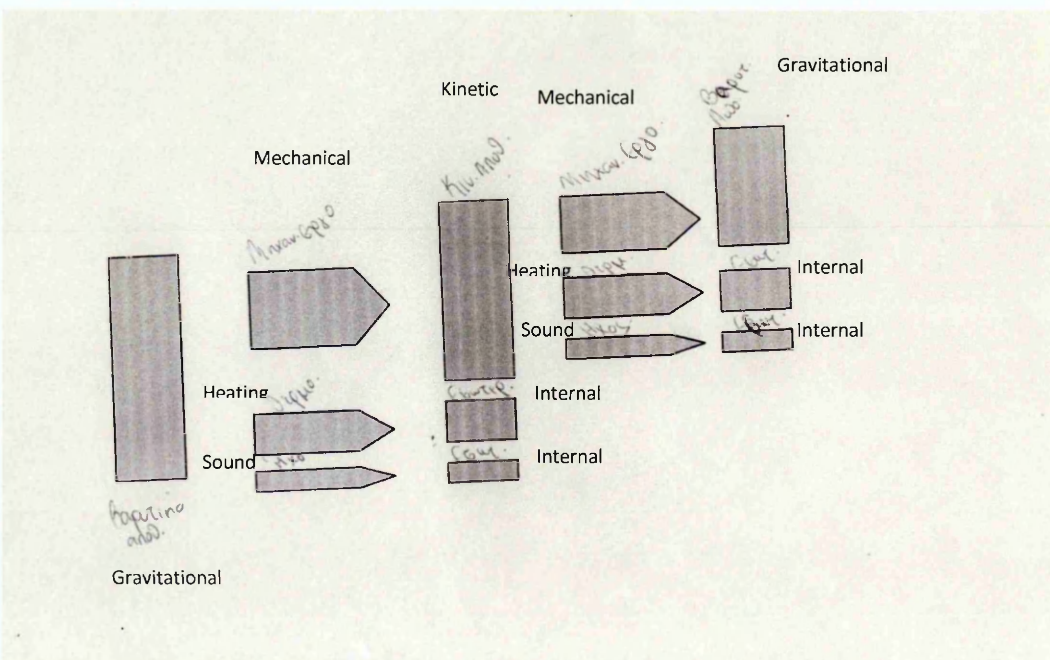
I: Tell me, what do you understand with the term 'degradation of energy'?

R: That it is reduced.

The above part suggests that the student considers the degradation process as energy 'loss' or 'reduction'. Moreover, it seems that only the energy of the ball is taken into account and not the energy of the system. This might be attributed to a difficulty in understanding of the ideas of a system and of energy as a property of it.

In the following, the student chose the correct diagram for this system (see, Appendix E) and completed correctly the corresponding energy stores and transfer pathways. Her response and the Full Sequence Energy Diagram were as follows:

> *I:* Ok. Now lets see two diagrams. … Which of the two diagrams represents best the process in the system in terms of energy?
>
> *R:* E … lets start from gravitational …
>
> …….
>
> *R:* I will choose this diagram.
>
> *I:* You choose this one.
>
> *R:* For the reason that from point A to point B we have the gravitational store, which is transferred along a mechanical working pathway and also we have the internal where in the internal sound and heating is stored. It is transmitted again along a mechanical working pathway … .
>
> *I:* Lets consider BC as one part, ok?
>
> *R:* Yes, kinetic store and we have again the gravitational in which it is transmitted again along sound and heating.
>
> *I:* Would you like to write them on the diagram? What do you think?



In completing the diagram, the student did not seem very confident and there were cases at which clarifying questions were posed by the researcher. One such case was the following:

I: Where the energy which is transferred along a mechanical working pathway go?

R: In the kinetic store.

I: Which of these is the kinetic, which of these three is the kinetic?

R: This one, the first piece.

I: So you shouldn't write it down there.

R: ... kinetic store and this goes in the internal.

I: You say that this goes to the internal. Where does heating go?

R: Again in the internal.

The above part and other parts of the interview suggest that the student was still finding some difficulty in linking the energy representation with the appropriate parts of the events. Moreover, it seemed that the fact that the diagram was given helped the student to eventually link the events with their energy description and complete the diagram correctly. However, it seemed that there was some understanding of the kinds of energy stores and pathways involved in the physical process within this system.

In addition, referring again to the student's understanding of the degradation of energy aspect, although she specified correctly heating and internal store as the pathway and the store respectively in which the energy of the system is transferred and stored at the end and also the places at which it can be found, it seems that this was not seen as the degradation process.

The student was asked then about her understanding of the energy stores and transfer pathways. Her responses were as follows:

I: Ok. Tell me, what the rectangles represent on the diagrams?

R: The energy which is exerted, how much energy is exerted in each store.

I: Ok.

R: So, for point B we have a bigger rectangle for gravitational store, it is transmitted along mechanical working, again we have kinetic at AC which is smaller store than gravitational and finally CD which is smaller even than gravitational and kinetic and thus this is smaller.

I: Whereas the arrows what do they represent?

R: How this energy is transmitted and we have mechanical working and in the internal sound and heating.

Although the student used the force related word 'exerted' in order to express her conceptions of an energy store it seems that, there is an understanding of both the ideas of energy stores and the transfer pathways. Furthermore, this might be attributed to a difficulty in formulating her responses using the appropriate words.

The next question posed to the student concerned her understanding on the conservation of the energy of this system:

> *I:* After the marble comes to rest, at BC part, what do you think happens to the energy?
>
> *R:* There isn't any energy.
>
> *I:* There isn't any energy. Tell me now, with respect to that diagram, what do you think about the initial and the final energy?
>
> *R:* We see that initial energy is plenty, is much, whereas we see that at the end there isn't much energy. That's it.
>
> *I:* So, how do you compare this with energy in the end? The initial energy with the final energy?
>
> *R:* I believe that in the initial energy there isn't any sound, it is not splitted.
>
> *I:* Yes ...?
>
> *R:* But we see that in the end, there is a gravitational store and internal store in which it is transferred along sound and heating.
>
> *I:* Ok. But how about the total energy at the start and at the end?
>
> *R:* I believe that energy remains the same.
>
> *I:* In total?
>
> *R:* In total.

As in the case of the degradation aspect, it seems that the student considered at first the conservation of the energy of the ball solely and not the conservation of the energy of the system. However, a further probing revealed that there is an understanding of the conservation of energy aspect.

Finally, the student was asked about her understanding of the nature of energy and its role in science:

> *I:* Mm. Tell me, energy stores and transfer pathways exist? That is, can we perceive them, can we …
> *R:* No, we can't perceive them, however physicists gives us these theorems.
> *I:* Why do you think that we use them?
> *R:* In order to see every activity we perform or in our environment where these stores are and we can't see them.
> *I:* That is, we use them to explain or to interpret, what do you think?
> *R:* To interpret every activity is done by humans.
> *I:* Only by humans?
> *R:* No, and in the environment in which all are active.

The above student's responses suggest some understanding of the abstract nature of energy and its interpretive role in science.

Overall, Amalia's responses on the questions of this interview suggest a shift in her understanding of the energy ideas compared to that of the first probe. This shift is mainly focused on the conservation aspect of energy whereas there no understanding of the degradation aspect was acquired by the student at this point.

Second short-length diagnostic probe

Amalia's responses on the first two questions of the second diagnostic probe concerning the ideas that mechanical working done and the amount of energy in the gravitational store do not depend on the pathway followed but only on the vertical distance between the two positions were as follows:

> *'I disagree because mechanical working done will be the same no matter which way the worker will choose to follow.'*

and

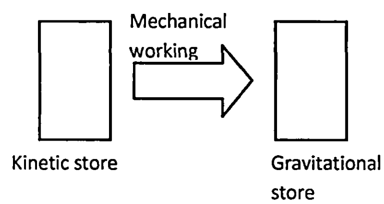
> *'I disagree because the energy in the gravitational store will be the same no matter which way will be chosen by the worker to follow.'*

Although the student did not explicitly justify her responses it seems that there is some understanding of these ideas.

The student's responses on the questions concerning the verbal and the diagrammatic energy description of the physical process of the system were as follows:

> *'Kinetic store → transmitted along mechanical working to the gravitational store.'*

and



The above verbal and diagrammatic energy descriptions clearly suggest that only the energy of the box was taken into consideration by the student and not the energy of the system. Again, it seems that there is difficulty in understanding the ideas of a system and of energy as a property of it.

Amalia's response on the last question, although solely referred to the box and not to the system, reveals some understanding on the conservation and the degradation aspects of energy. Her response was as follows:

> *'I disagree because there is the same amount of energy in the gravitational and the kinetic store, because there is no friction that is no transfer along sound and heating to the internal store.'*

Furthermore, the student's responses on the questions of this probe suggest a shift in her understanding of the energy concept compared to that in the first interview, which is mainly focused on the conservation and the degradation aspects of energy.

Second interview

Concerning the first question, the student's verbal energy description for the system (golf player-ball system) was as follows:

> *I:* Fine. Tell me, if you would describe it in terms of energy …

R: Yes.

I: … the process. How could you describe it?

R: Initially there is a chemical store, hence the chemical store is transferred along a mechanical working pathway to the kinetic store and we see that the ball stops and it goes to the internal store.

I: How energy is transferred from the kinetic to the internal?

R: From the kinetic to the internal?

I: Yes, from kinetic to the internal.

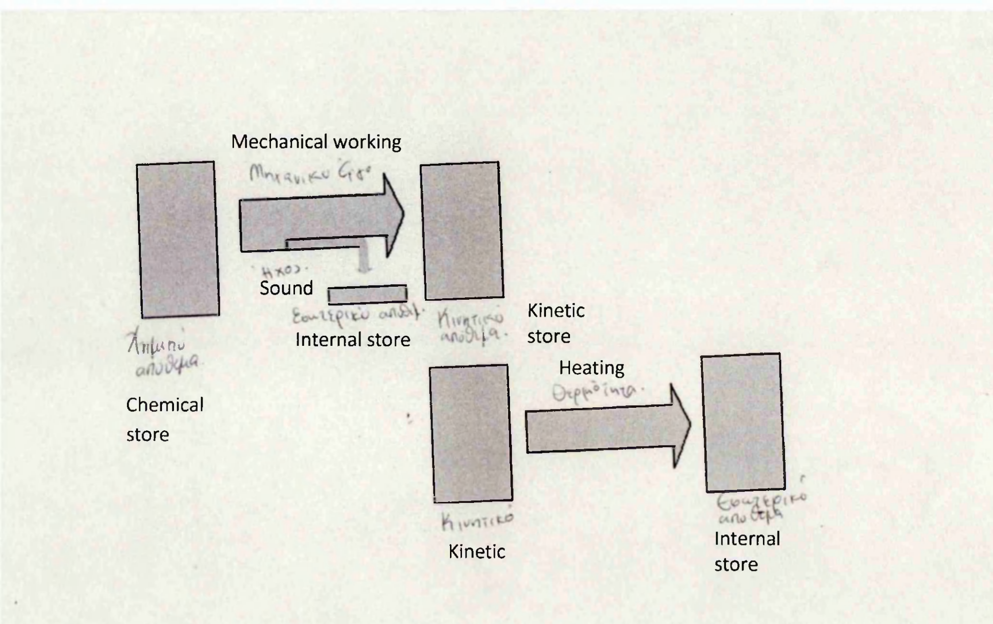
R: E, I think it is transferred to the internal along a heating or a sound pathway.

I: Which of the two do you think that it is, heating or sound?

R: Heating.

The above part suggests an understanding of the ideas of energy store and transfer apart that sound is not specified as a pathway along which the energy is transferred from the chemical to the internal store. Furthermore, it seems that the student did not find difficulty any further in linking the physical events with the appropriate parts of the energy description nor to sequence the energy events in the right order.

Then, the student chose the correct diagram (see, Appendix F) for this system and completed correctly and with confidence the energy stores and transfer pathways. Her response and her diagram were as follows:



The next question posed to the student concerned the conservation of energy of the system:

> *I:* Ok. Tell me now, if you would compare the total energy of the system at the start and at the end, what would you tell me?
> *R:* That energy is constant.
> *I:* The same?
> *R:* Yes, the same.

The above response suggests an understanding of the conservation of energy aspect. Then the student was asked about her understanding of the degradation of energy aspect. Her response was as follows:

> *I:* Tell me now, you told me that here, energy is transferred along a heating pathway, is it right?
> *R:* Yes.
> *I:* Where this energy goes?
> *R:* Where is it go?
> *I:* Yes, you told me in the internal store but in order not to confuse you, where this internal store can be found in the system? In the physical system?
> *R:* In the physical system?
> *I:* Yes.
> *R:* In the ball.
> *I:* In the ball.
> *R:* ... and in the ground on which it rolls.

From the above part it seems that there is some understanding of the degradation of energy aspect although surrounding air is not specified as another place at which an internal store is found.

The last two questions posed to the student concerned her understanding on the nature of energy and its role in science. Her responses were as follows:

> *I:* Mm. tell me, energy stores and energy transfer pathways exist?

R: They don't exist in nature but us the humans use them in order to elaborate ...

I: The physical processes?

R: Yes.

I: So, what would you tell me if I would ask you what energy is? Is it something ...

R: Energy exists but we can't see it.

I: Yes ...?

R: There is energy in every activity.

I: Yes. Why do we use energy in physics?

R: To understand some ... to interpret ...

Regarding the nature of energy, the student's response suggests a materialistic view of energy and it seems to be differentiated from the abstract view expressed in the first interview. Furthermore, her view about an interpretive role of energy in science did not seem to be changed compared to that in the first interview.

Post-test

On the question concerning the student's ability in interpreting the event of the simulation (spring-ball system) in terms of energy, the student responded as follows:

> *'The ball is in front of the spring and once the spring stretches the energy goes to the ball and then to the internal store of the ball.'*

Comparing the above response to the corresponding one in pre-test it seems that, the student abandoned her initial 'activity' model views and interpreted the events in terms of the energy ideas introduced in the 'new approach'. Furthermore, it seems that the student did not find difficulty in sequencing the events in the right order and linking them with the energy transfer within the system. However, in her energy description not all the energy stores and transfer pathways were specified.

Another response on which an interest might be focused concerns the student's understanding of the conservation of the energy of this system:

> *'At the beginning there is energy in the spring and once the spring pushes the ball the energy decreases and there isn't any at the end.'*

The above response suggests that there isn't an understanding of the conservation of energy aspect as the corresponding response in pre-test also suggested.

However, the student's response on the conservation of energy of the system of the stopping car in the post-test part B is interesting. This was as follows:

> *'At the beginning at point A it is* (the energy) *in the kinetic store whereas at point B the energy goes to the internal store. The amount of energy in both stores is the same.'*

The above response clearly suggests an understanding of both the conservation and the degradation of energy aspects.

From the previous discussion it seems that, there is a difficulty in transferring the knowledge on the conservation aspect in different systems rather than a difficulty in understanding the specific idea; in some systems, the student tended to consider the conservation of the energy of the individual parts of the system and not the conservation of the energy of the system. This, is more obvious in more complicated systems, with more than one moving parts such as the spring-ball system or the two-situation system of the skier, whereas in simpler systems such as that of the stopping car the student did not demonstrated any difficulty. Moreover, it seems that this difficulty has its roots on a difficulty in understanding the ideas of a system and of energy as a property of it.

Turning to the student's energy description, it suggests a shift in her understanding of the energy ideas introduced. This was as follows:

> *'At the beginning the energy is in the spring and hence the spring stretches and pushes the ball and the energy is transferred along a mechanical working pathway and then it is transferred to the internal store of the ball along a sound and a heating pathway.'*

The student's energy description is correct and almost complete since the elastic and the kinetic stores are not specified. Also it should be remarked that, the student did not respond to the question in pre-test which suggested a difficulty in formulating any energy description for the event of the simulation.

Furthermore, Amalia's overall achievement on the post-test part B questions revealed a difficulty in transferring the acquired knowledge on energy in the quantitative ones. In particular, the student responded only to those quantitative questions in which the simple substitution on the calculating formula of the amount of energy in an energy store was required. In those questions in which a more sophisticated reasoning and a more complicated mathematical treatment was required, as in the cases of the mechanical working-kinetic store theorem and the conservation of mechanical store theorem, the student did not respond.

Overall description of the energy learning profile

At the start, Amalia formulated an interpretation of the event of the simulation which was a force based one, referring to the 'activity' model of energy whereas she did not formulate any energy description of the event.

On the questions of the first probe, the student abandoned her initial views and formulated her responses in terms of the energy ideas and terminology introduced in the 'new approach'. However, her responses suggested a difficulty in sequencing of events of a physical process and a difficulty in linking her energy description to the appropriate parts of the event. Furthermore, they suggested that little understanding was acquired at this point on the conservation and degradation aspects of energy.

The student's responses on the questions of the first interview, although made with not much confidence and in confusion in some cases, suggested a shift in her understanding focused on the conservation of energy aspect. Though, she tended to take into consideration the conservation of energy of an individual part rather the conservation of energy of the system. This might be attributed to a not well established knowledge of the ideas of a system and of energy as a property of it. Turning to the degradation of energy aspect, although the student specified correctly in her energy description the internal store as the store in which the energy of the system is stored at the end and heating and sound as transfer pathways along which it is transferred, she did not demonstrate an understanding of this as the degradation process. Furthermore, the student expressed views about an abstract nature of energy and an interpretive role in science.

On the questions of the second probe, the student's responses suggested a shift in her understanding on the conservation and the degradation aspects of energy. Also, they provided once again an evidence of a difficulty in understanding of the idea of a system since her energy description was focused on the moving part of the system.

Amalia's responses on the questions of the second interview were made with confidence and revealed a further shift in her understanding of all the energy ideas introduced. The student did not seem to have a difficulty in sequencing the physical events or linking them with the appropriate parts of the energy description. However, she seemed to differentiate her views on the nature of energy by expressing a materialistic view whereas she expressed again about an interpretive role of energy in science.

Finally, the student's responses to the post-test's questions revealed that the shift in understanding of the energy concept demonstrated in the second interview was stable. The student formulated an interpretation of the event of the simulation in terms of energy and an energy description using the energy ideas introduced in the 'new approach'. Though, they revealed a difficulty in transferring the acquired knowledge in different systems, as in the case of the conservation of energy aspect. This difficulty was apparent in more complicated systems with more than one moving parts or with two-situation events; the student tended to take into consideration the conservation of an individual part and not the conservation of the energy of the system. Furthermore, this might be attributed to a not well established knowledge on the ideas of a system and of energy as a property of it. In addition, a difficulty in transferring the acquired knowledge in quantitative applications was demonstrated. The student responded only to those questions in which the simple substitution of the data on the calculating formula of the amount of energy in an energy store was required; in those questions where more sophisticated reasoning and mathematical elaboration was required such as in the case of the mechanical working-kinetic store theorem and the conservation of mechanical store theorem, the student did not respond.

6.3.3 The student's response to the 'new approach'

Amalia responded with enthusiasm to the new approach of teaching energy and seemed keen to do her best from the beginning of the teaching sequence. She was an active learner in all lessons and did not seem to be disturbed by the presence of the video camera.

When the class was asked for volunteers to be interviewed, Amalia was among those who volunteered. At the end of that lesson, she approached the researcher and had an informal discussion about her achievement in physics. She informed the researcher that she is a low achiever in physics but not because she is not interested for the subject but because she finds a great difficulty in understanding it. Furthermore, she expressed her enthusiasm about the innovative material which 'help low achievers like myself to understand physics'. In particular, she expressed the opinion that the visual representations, the images and the simulations make the lessons more exciting and understandable.

STUDENT 4: Andreas

6.4.1 Background

Andreas is a high achievement student with an interest in science subjects. As with the majority of the students in his class, he did not seem to have much knowledge of energy from formal instruction prior to the experimental intervention.

In the following, Andrea's energy learning profile is presented and commented.

6.4.2 Energy learning profile

The energy learning profile was developed with data from the pre-test, interviews and post-test.

Pre-test

Andrea's interpretation of the event of the simulation was force based and was as follows:

> *'A force is exerted on the spring and then an opposite greater force is exerted on the ball by the spring.'*

For the next questions, whether there is energy at the beginning and where, the student's responses suggest some understanding of the spring as an 'energy store' and that the energy was stored in the compressed spring:

> *'Yes.'*
>
> *' Where the spring is compressed.'*

The student's response on the question concerning the energy of this system at the end was as follows:

> *'No.'*
>
> *' Because it* (probably the ball) *stopped moving.'*

The above response suggests that there isn't an understanding of the conservation aspect of energy. In addition, this suggests that energy is associated with motion which provides evidence about initial ideas within the 'activity' model of energy. Moreover, the lack of understanding of the conservation of energy aspect is also demonstrated in his response to the question to compare the amount of energy at the end with that at the beginning. His response was as follows:

> *'It is less.'*

Finally, the student formulated a very brief energy description which was as follows:

> '(The energy) *It increased and at the end it disappeared.'*

Although the above energy description is a very brief one, it provides evidence about ideas within the 'product' energy model according to which energy is considered as a kind of by-product of a situation that is generated, is active, and then disappears or fades.

Overall, the student's responses to the questions of the pre-test reveal initial ideas on energy which relate to the 'activity' and the 'product' models of energy.

First interview

Regarding the first question of the interview, aimed to reveal the student's understanding of the degradation of energy of the system (metallic rail-marble system), Andreas chose the correct point D (see, Appendix E) for where the marble would reach after it would released at point A:

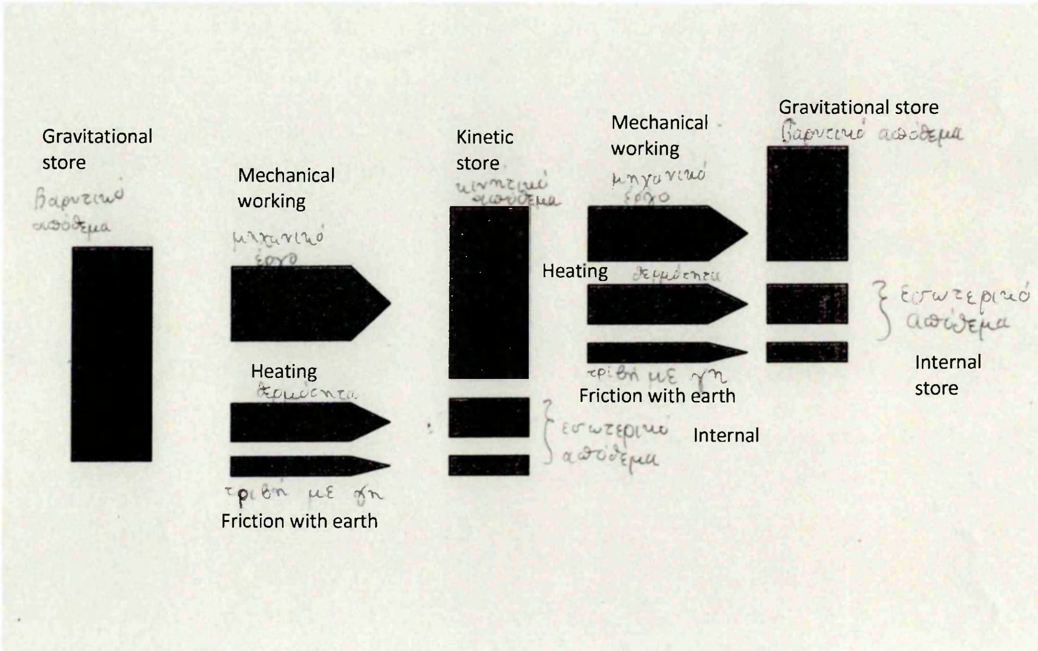
> *I:* ... With which of the two do you agree?
>
> *R:* E, do we consider that there is heating and …
>
> *I:* As is illustrated in that system, we let a marble roll on a metallic rail, ok? What do you think?
>
> *R:* I believe that it will reach point D.
>
> *I:* Why do you think that it will reach point D?
>
> *R:* It will go to the internal store … It will not reach point E. Energy will go and somewhere else.

The above part suggests some understanding of the degradation of energy.

The extent of the student's understanding of the degradation aspect was further demonstrated as follows:

> *I:* ... Andrea, you told me that the marble will reach point D, is that right? If we let it to move further …
>
> *R:* It will reach up to here and finally it will stop here (the student pointed to the lower part BC).
>
> *I:* Is any energy there?
>
> *R:* Yes, it simply can't be used any further.
>
> ……………
>
> *I:* ... Tell me, where can an internal store be found in the system?
>
> *R:* Where is the internal store?
>
> *I:* Yes.
>
> *R:* It is in the environment, in the air, in the ground …
>
> *I:* Tell me, do you remember how the process with which energy is transferred along heating in the environment is called?
>
> *R:* No. I don't remember definitions.

The student then chose the correct diagram for this system (see, Appendix E) and completed correctly the corresponding energy stores but some difficulty was demonstrated concerning the transfer pathways. His response and the Full Sequence Energy Diagram were as follows:



As can be noticed, sound was not specified as a transfer pathway of energy to the internal store. However, it is interesting that heating and friction were considered as two different pathways of degrading energy:

> *R:* The first is heating, the other is friction with Earth.
>
> *I:* Tell me, are heating and friction with Earth stores or transfer pathways?
>
> *R:* Transfer pathways.
>
> *I:* If they are transfer pathways, where would you write them?
>
> *R:* … (The student wrote the pathways on the diagram).
>
> *I:* Ok. What do you mean here, 'friction with Earth'? What do you mean in terms of energy?
>
> *R:* That there is energy transfer along that pathway to the internal.

The above part suggests that at this point, there was confusion concerning the pathways along which the energy is transferred to the internal store. Then, the student was asked about his understanding of the energy stores and transfer pathways. He responded as follows:

> *I:* Mm. In general, what do the arrows represent in an energy diagram?
>
> *R:* The way with which energy is transferred from one store to another.
>
> *I:* Ok, whereas the rectangles, what do they represent?
>
> *R:* The energy, the energy stores.

From the above part it seems that there is an understanding of both ideas. The extent of the student's understanding of the above ideas is further demonstrated as follows:

> *I:* The stores. Fine. Now tell me Andrea, why are some stores, some rectangles are large and some small?
>
> *R:* Because there is energy in that place, it does not disappear from the place, it transfers from a store to only one other store but there is heating and working, that's why it is split to other stores, it will not go straight forward to the kinetic …

The next question posed to Andreas concerned the conservation of the energy of this system. His response was as follows:

> *I:* Now, if I would tell you to compare the energy of the system at the beginning and at the end, what would you tell me?
>
> *R:* That it is the same.

The above part reveals an understanding of the conservation of energy aspect.

In the following, the student was asked about his understanding on the nature of the energy concept and its role in science:

> *I:* Tell me Andrea, do you think that energy stores and transfer pathways exist?
>
> *R:* Do you mean in real life?

I: Yes, is it something which exists?

R: We can't feel them but they exist.

I: Energy exists?

R: It exists. Without energy there will not be any action.

I: That is, what is the reason of using energy in physics?

R: In experiments you mean?

I: In general, for example we used energy for that system. Why do you think?

R: To explain the movement with energy.

The above responses suggest a materialistic view of energy and an explanatory role of it in science.

Andreas' responses on the key questions of the interview suggest a development in his understanding of the energy concept compared to its initial 'activity' and 'product' ideas expressed in the pre-test. Furthermore, the student seemed to adjust to the terminology and the energy ideas introduced in the 'new approach'.

Second interview

The first question posed to Andreas concerned the extent of his ability in interpreting verbally in terms of energy the physical process of the system (golf player-ball system) and to represent it diagrammatically. His verbal energy interpretation and the corresponding Full Sequence Energy Diagram of the system were as follows:

I: That is, can we interpret this process using energy?

R: The chemical store is transferred along a pathway, working, to the kinetic store and hence to the internal store and the ball finally stopped.

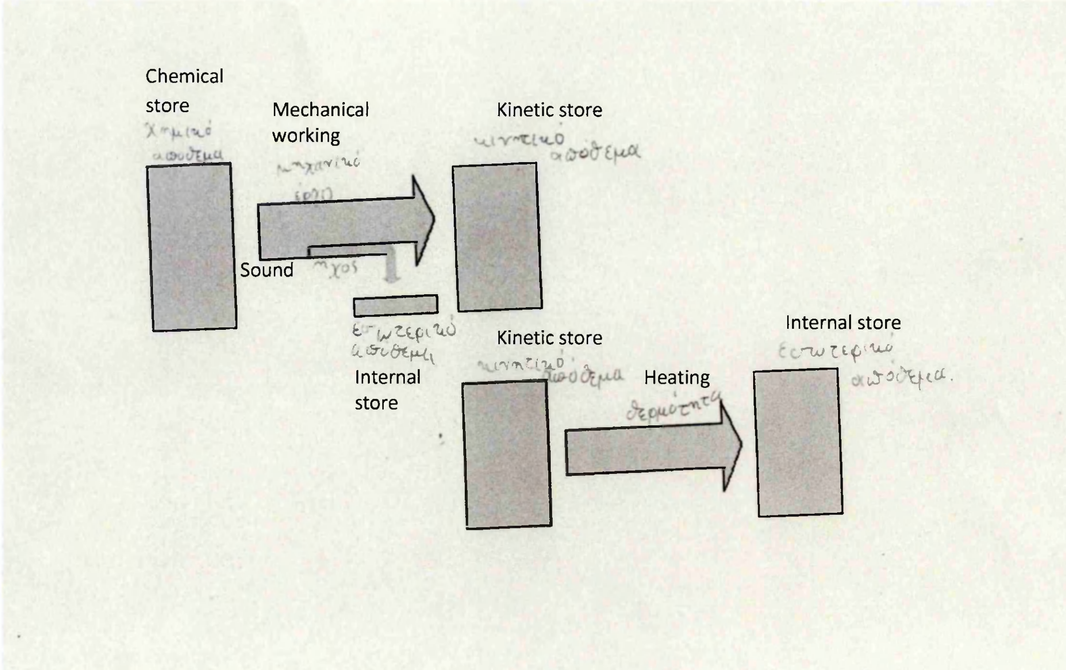
I: How is energy transferred to the internal store?

R: Along heating.

I: If now I would tell you to choose between these two energy diagrams, which one would you choose for that system?

R: This one.

I: That one. Earlier you made a fine description. Can you write the energy stores and the transfer pathways on the diagram?



The above responses suggest ability in interpreting verbally a physical process in terms of the energy model introduced and in representing it diagrammatically.

The next question aimed to reveal the student's understanding of the degradation of the energy of this system:

> *I:* Ok. So chemical store is finally stored in the internal store being transferred along those pathways. Can energy in the internal store be further used?
>
> *R:* For a new movement?
>
> *I:* For any other physical process.
>
> *R:* No, I don't think so, I can't think of how energy in an internal store be further used.
>
> *I:* Do you remember how this process is called in physics?
>
> *R:* Degradation of energy.

From the above part it seems that there is an understanding of the degradation of energy aspect. Moreover, the student's response on the question regarding the conservation of the energy of this system was as follows:

> *I:* And how does the energy in the chemical store compare to that in the internal store?

internal store?

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R: They are the same.

The above part reveals an understanding of the conservation of energy aspect.

Andrea's responses on the questions of this interview were made with some confidence and provided evidence of a shift in his understanding which is mainly focused on the energy transfer pathways. In particular, the student specified correctly heating and sound as the transfer pathways along which the energy of the system is transferred to the internal store.

Post-test

Andreas responded to all the post-test's part A and part B questions. In order for the extent of the student's understanding to be demonstrated, his responses on two of the key questions of post-test's part A, the corresponding of which were discussed earlier for the pre-test, will be followed.

The first, concerns the student's ability in interpreting the event of the simulation (spring-ball system) in terms of energy. His response was as follows:

> *'The spring was compressed by a force which was exerted on it and as it was let to stretch it pushed the ball and transferred the energy which was in its elastic store to the kinetic store of the ball. At the end the ball came to rest because the energy was transferred to the internal store of the ground and the air.'*

Comparing the above response with the corresponding in pre-test, it seems that there is a significant development in the student's understanding of the energy concept since the student abandoned his 'activity' model ideas and interpreted the event of the simulation in terms of the energy ideas introduced.

The second question concerns the student's ability in formulating an energy description of the event of the simulation. His response was as follows:

> *'The energy was in the elastic store of the spring and then it was transferred along a mechanical working pathway to the kinetic store of the ball and then to the internal store of the air and the ground.'*

Although the student did not specify sound and heating as the transfer pathways along which the energy is transferred to the internal store, this response suggests an understanding of the energy ideas introduced. Moreover, this response compared to the corresponding in pre-test provides evidence of development in the student's understanding of the energy concept since it seems that the student abandoned his initial 'product' model ideas.

Another response which might worth to be discussed concerns the energy description of the system of the stopping car for distance AB in part B of the post-test. This was as follows:

> *'The energy was in the kinetic store of the car and along a mechanical working pathway it was transferred to the internal store of the air and the ground.'*

Although the above response suggests an understanding of the degradation aspect of energy, mechanical working pathway is specified erroneously instead of heating. Moreover, this suggests confusion between the mechanical working and heating pathways in the case of the energy transfer to the internal store in the degradation process.

Overall description of the energy learning profile

Andreas' initial interpretation of the event of the simulation was force-based and his views on energy within the 'activity' and the 'product' models respectively.

In spite the fact that the student attended only two of the three lessons in which the energy model was introduced, his responses on the questions of the first interview suggested a significant improvement in his understanding of energy compared to that at pre-test. The student seemed to abandon his force based initial views and fully adjusted to the ideas and terminology of the 'new approach'. Some difficulty in his understanding was demonstrated concerning the transfer pathways to the internal store since friction was specified as a pathway along with heating; whilst, sound was not specified. In addition, regarding the nature of energy and its role in science, the student expressed views about a materialistic nature and an explanatory role of energy.

For the questions of the second interview, Andreas' responses were made with some confidence and suggested a shift in his understanding on all the energy aspects. Moreover, it should be remarked that, the student attended only three of the five lessons between the first and the second interview.

Finally, the student's responses on all the post-test questions suggest a good understanding of the energy concept and the ability to transfer the acquired knowledge to various systems both qualitatively and quantitatively. Some confusion was demonstrated regarding the mechanical working and heating pathways in the case of the energy transfer to the internal store in the process of the degradation of energy.

6.4.3 THE STUDENT'S RESPONSE TO THE 'NEW APPROACH'

Andreas showed an interest about the 'new approach' from the first lessons and kept a positive attitude during the teaching sequence. In an informal discussion with the researcher at the end of the first interview, he expressed the opinion that the approach was an interesting one in learning physics. Also, the student had an informal discussion with the experimental group teacher and the researcher at the end of the last lesson in which he asked to be informed about the professional opportunities of studying physics apart of becoming a physics teacher.

Due to his engagement with the volleyball team of the school, the student did not attend all of the lessons of the teaching sequence since he had to follow the team in games abroad. However, this did not seem to affect his interest and achievement on the physics lessons. He was an active learner in the lessons in which he was present and in some cases he was addressing a lot of questions to the teacher; for this, he was apologizing to the teacher saying that 'I am trying to understand'. Furthermore, the student did not seem to be disturbed by the presence of the video camera during the lessons.

Andreas completed the pre-test on the next day to the rest of the experimental group since he was absent in a volleyball game and did not take the two short diagnostic probes for the same reason. The student was not asked to take the probes at some other time in order for his school attendance not to be further disturbed. However, when the class was asked for volunteers for interviewing, he was among the volunteers.

II. TEACHER RESPONSES TO THE EXPERIMENTAL TEACHING

Data collected from the experimental group teacher was exposed to a thematic analysis selecting ideas which concerned the teacher's views on the strengths and the weaknesses of the teaching material, the students' attitudes towards the 'new' approach and the impact on their learning, of her teaching of specific issues as well as an overall evaluation of the research-informed teaching sequence.

In the following, each theme is presented with a commentary.

6.5.1 SUCCESSFUL ASPECTS OF THE TEACHING SEQUENCE

At the start of the interview, the teacher was asked about the first lesson of the teaching sequence. She expressed the following view:

> *R:* Well, I think that the first lesson was very important. All the essence of the sequence was included in that and the way of introduction was very nice, the simulations were impressive, I think that the students liked it.

With the above view, the teacher raised two main issues: on one hand, the importance of the content of the first lesson in which the key elements of the energy model and the new terminology are introduced; on the other hand, the motivating way of initiating the introduction of the energy ideas with the use of simulations and the Interactive/Dialogic approach which, as she noted, succeeded in raising the students' interest.

In proceeding to the next question, concerning the introduction of the conservation of energy aspect and the verbal and diagrammatic representation of the energy transfer in a physical system, the teacher responded as follows:

> *I:* Fine. What about the second lesson?

R: In the second lesson, the Sankey diagrams and the idea of conservation of energy have been introduced...

I: ... what about the content, the way of introducing energy, do you think that it is effective, that it promotes understanding?

R: I believe yes and the simulation for presenting the idea of conservation of energy was a successful one.

....

R: ... I think that the students didn't find any difficulty, I think that they were able to draw the diagrams easier because the description had been preceded, the verbal energy description, the diagram had been followed and thus it was easier to be drawn.

From the above part it seems that the teacher considered the content of the simulation used in addressing the conservation of energy idea as effective in terms of conceptual understanding. Furthermore, it seems that she considered the order in which the descriptions were introduced, with verbal presentation followed by diagrams, as an effective one also.

In the following, the teacher also expressed positively about the content of the simulation used for the introduction of the degradation of energy aspect. Her view was as follows:

I: What about the third lesson?

R: In the third lesson the idea of degradation is introduced. I believe that the simulation was very good, it was a suitable one for introducing the degradation of energy, although students did not understand the idea of degradation at first and we had to emphasize some more, but in the end, most of the students understood degradation.

In another part of the interview, the teacher expressed a more general view about the use of visual representations in relation to promoting conceptual understanding of the energy ideas as follows:

R: Yes, if visual means and visual representations were not used in the teaching procedure, they might not succeed in understanding some things. Provided that they don't study much, they succeeded in learning a lot …

The above part suggests that the teacher considered the use of visual representations in the teaching and learning procedure of the energy ideas as an effective educational tool regarding two aspects: they enhance understanding of difficult abstract ideas such as those related to the energy concept to become understandable and, they enhance learning of the energy ideas even if the students did not put much effort on individual study.

The next question posed to the teacher concerned the content of the handouts and the worksheets of the first three lessons in particular which consist the core of the 'new' approach.

I: Do you think that there is something in the worksheets or the handouts for the first three lessons that should be improved besides the chemical and the …
R: In the worksheets no, they are very good, detailed as they are. For the first three lessons yes, they are very good, yes I believe that the second and the third ones were very good. The handouts were quite good and the worksheets, yes.

From the above response it seems that the teacher considered both the content and the extent of the handouts as quite satisfactory in presenting the energy ideas introduced in the lessons by characterizing them as 'very good, detailed as they are'. In addition, it seems that she considered the proposed tasks in the corresponding worksheets as suitable in supporting learning of the energy ideas presented in the handouts.

Then, the teacher asked about another important part of the teaching sequence, the lessons in which the idea of mechanical working is introduced, on which the mathematical verification of the calculating formulae of the various energy stores is based on.

> *I:* What about the rest, the next two lessons which concern mechanical working?
> *R:* The lessons about mechanical working are quite good. The fourth lesson about working, yes I believe that it was ok and the fifth was quite good. I believe that these two do not need any improvement, they are quit good.
> *I:* What about the exercises?
> *R:* The exercises were suitable.

Regarding the two lessons, the teacher seems to express the view that both the content and the classroom talk were quite satisfactory for addressing the idea of mechanical working. Furthermore, on commenting on the corresponding handouts, she considered the exercises comprised in them as 'suitable' to support learning of the idea.

In the next question, the teacher asked about the lessons followed the introduction of the mechanical working idea. Her views were interesting:

> *I:* Then, the study of the stores one by one started. What do you think about the structure?
> *R:* Yes, I believe that the correlation of all energy stores with mechanical working is successful, that is, the students understand how each calculating formula derives from … by performing the verification which I think is something good.
> ....
> *R:* I believe that the mathematical verifications are useful. It is not useful to introduce the students with a formula coming from nowhere and tell them that's how it is.
> *I:* Fine. That is, if we want our students to have a deeper insight to the concept of energy …
> *R:* Otherwise we can just present them the formula, yes, I believe that they are benefited by performing the verification.

In the above part, the teacher seems to advocate for the usefulness of performing the mathematical verifications of the calculating formulae of the kinetic, gravitational and elastic stores in the learning procedure of energy. In particular, she had focused on the fact that the verifications have as a starting point the new ideas of energy stores and the mechanical working pathway and also, the conservation of energy idea, and expressed the view that they promote understanding of the calculating formulae. Furthermore, it seems to express also the view that the simple memorization of the formulae can be avoided in that way.

Apart from the content, the structure and the means used in the teaching sequence, the teacher also asked about the communicative approach used. She responded as follows:

> *I:* Fine. What about the kind of classroom talk that you used to present the ideas?
> *R:* The ways of teaching?
> *I:* Yes, the interactive dialogic, the …
> *R:* Yes, I think that they were quite good.
> *I:* Do you think that they are effective?
> *R*: I believe that the students are not very familiar in that way but I think that they are quite good, that they should progressively get used to that way of teaching, especially in interacting with each other.

And in another part of the interview:

> *I:* What about the kind of classroom talk again which has been used and …
> *R:* I think that the students participated to the talk. I think that they understood the verifications, they understood the correlation, how the calculating formula for each store derived starting from mechanical working.

The above parts suggest that the teacher considered the use of the four classes of communicative approach as effective in the learning procedure and that they promoted understanding of the energy ideas. She expressed the view that communicative approach should be used in science teaching and furthermore, she seemed to particularly appreciate the Interactive/Dialogic class.

6.5.2 ASPECTS OF THE TEACHING SEQUENCE WHICH NEED TO UNDERGO IMPROVEMENT

Having underlined the importance of the first lesson at the start of the interview, the teacher commented on that with some detail and suggested improvements. The first issue on which she commented on concerned the way of introducing the chemical and the internal stores in both the simulations and the handouts. Her views were as follows:

> *R*: ... The only thing that I think that need some further explanation concerns the internal and the chemical store.
>
> *I:* Should the content of the handout be improved?
>
> *R:* Yes, some further explanation is needed.
>
> *I:* What about the corresponding simulations?
>
> *R*: The simulation about internal store needs I think some more … to be improved somehow, I don't know, in order to be more understandable.
>
> *I:* Fine. That is, should be made a change in content?
>
> *R:* Maybe yes or it may not change, just to be explained more, both of them …
>
> *I:* In the handout?
>
> *R:* Yes in the handout I presume and to be explained using examples too.
>
> ....
>
> *R:* And some confused at first internal store with chemical store. Maybe because the simulations have something in common, I think that both were presenting molecules …
>
> *I:* Yes, yes.
>
> *R*: … it maybe that the reason of confusion. If a way could be found so these to be differentiated a little bit in order the students to understand the difference between them.

As the teacher reported, there was some confusion and a difficulty in understanding of the chemical and the internal stores among students which she attributed to the way of introducing them both in the simulations and the handout. As far as it concerns the simulations, she suggested that a kind of improvement should be made in the content in order the chemical and the internal store ideas to become explicit and also enable the students to differentiate between them. Regarding the handout, her suggestion was rather a more detailed presentation of each of these stores in which some worked examples to be included.

Furthermore, the teacher reported a difficulty in the students' understanding concerning the heating and the sound pathways. Her view was as follows:

> *R:* Some students have a problem in recognizing sound and heating, these two transfer pathways. They are not sure whether is sound or heating, a transfer along a sound pathway or a transfer along a heating pathway. They recognize mechanical working at once, they tell you that there is a transfer along a mechanical working pathway, but heating … they understand heating relatively better, sound less.
> *I:* Do you think that this has to do with the handout, with the way of presenting these transfer pathways? Or, do you spot the problem on something else?
> *R:* Maybe if an example was included in the handout about sound and one about heating also, but this is done afterwards, in the first lessons these transfer pathways did not become understood.

As in the case of the chemical and the internal store, the teacher suggested the enrichment of the handout with worked examples in order the heating and the sound pathway to become understandable to the students.

Another issue raised by the teacher concerning the first lesson was that of time. She expressed the following view:

> *R:* ... The worksheet took some more time I think that more time is needed for the first lesson.

In another part of the interview the teacher referred back to the first lesson with more comments, mainly on the issue of time, and suggestions for improvement as follows:

> *R:* I would like to add something concerning the first lesson. I think that the way of introducing every energy store is very nice but I think

that there should be some time available for discussing an example and see the energy changes in that specific example in class. That is, whereas the energy stores and the energy transfer pathways had been introduced in class, the completion of the worksheet had been assigned as homework. Students did not succeed to put together all these and to make an energy description. I think that some extra time of at least 10 minutes is needed in order a specific example to be presented and be described in terms of energy.

I: Fine. It is a thing that we should improve.

R: I don't know how this can be done in 40 minutes but it could be split in two lessons, the first one to include the introduction of the energy stores exactly as it is now and some time to dedicated for presenting a few examples in class in order the students be enabled to complete the worksheet in their own.

The key suggestion made by the teacher was the content of the first lesson split into two lessons. In the first lesson, the introduction of the energy stores and transfer pathways be performed in the way it was designed whereas in the second lesson, some worked examples be discussed in which these ideas be used for the energy description of the observed changes in various physical systems. In that way, according to the teacher's view, the students will enabled to assimilate the new energy ideas and furthermore enabled to complete the relevant worksheet.

The teacher asked about the time needed in the cases of the lessons for the study of the kinetic, the gravitational and the elastic stores respectively. She expressed the following view:

I: Now again, what about the time dedicated for the introduction of each store?

R: Concerning time, I think that we needed some more time for the discussion of the worksheets.

I: Fine.

R: ... or maybe, if the exercises, the sub-questions included in the worksheets were less, then we would maybe catch up with their correction in classroom.

I: Fine. Then we maybe shortened them a little bit ...
R: ... the number of sub-questions. Ok, theory cannot be omitted, some elements cannot be skipped but if one application is explained in order for the students to understand, then I don't think that a second or a third one is needed.

Here, the teacher expressed the view that instead of planning more time for the study of each energy store, another possible improvement might be to shorten the relevant worksheets by removing a number of sub-questions from the exercises. Furthermore, in the teacher's view if one certain issue is discussed in a sub-question, then no other similar are needed to be discussed.

The teacher raised the issue of time needed also and in the case of the introduction of the mechanical store idea and the conservation of mechanical store theorem. She expressed the following view:

I: Fine. In the next, we had the two lessons on mechanical store. How about it, how the students faced the idea of mechanical store, given that the teaching of the aspects of conservation and degradation of energy has been preceded? Was that helpful or what?
R: Surely was helpful but some perceived mechanical as a different kind of store. They didn't understand completely that is the sum of the two stores. Maybe some extra time is needed for mechanical store.

Then, the interviewer proceeded to further probing of the teacher's views on the mechanical store lessons as follows:

I: Do you believe that ... rather, do you spot anything in the teaching material, maybe in the handout or do you spot it only on time?
R: No, the handout was very good but I am not sure, if the handout was more brief? And the examples more? If we had the time to discuss more examples. And maybe an example in which the conservation of mechanical store theorem is not valid, it would be helpful.

I: That is to put some emphasis to degradation again.

R: Yes, using for example a numerical application.

I: Fine, to be one in which the theorem is not valid, to prove that is not valid with a numerical way also.

R: Yes. For example, it could be the case in which air resistance should be taken into account where it will be proved numerically that the conservation of mechanical store is not valid.

I: Fine, we can see that.

R: In the case of a parachutist for example.

According to the above parts, the teacher expressed the view that some more time might be needed for the introduction of the mechanical store idea since some students did not understand it at first. In the following, she suggested that some more time is also needed for the discussion of more worked examples concerning the conservation of mechanical store theorem in order the theorem be assimilated by the students. Furthermore, another interesting suggestion made by the teacher was the discussion of an example in which the conservation of mechanical store is not valid, as in the cases of events under real conditions, that is, in the cases of events in which the degradation of energy procedure takes place. In addition, she suggested that the relevant handout might be shorter.

6.5.3 THE TEACHER'S REFLECTIONS ON STUDENTS' RESPONSES TO THE 'NEW' APPROACH

The teacher asked about her views regarding the students' attitudes towards the 'new' approach. She expressed some interesting views not only about the students' attitudes but also about the impact on their energy learning.

I: ... So, do you have any comments, any remarks in general, about the teaching material as a whole or regarding the students' reactions?

R: I believe that the material is very good, especially the simulations included in the first lessons. I believe that they were very good and succeeded in causing some students' interest who I didn't expect to be interested. The increased interest due to the simulations was much more obvious among students of low and middle achievement and I noticed a significant improvement in those students ...

In the above part, the teacher reported an increased interest for the physics lessons mainly among students of low and middle achievement and an improvement in their learning. According to the teacher, a key role to the increase in both the students' interest and their improvement in learning was played by the simulations included in the first three lessons of the teaching sequence in which all the energy ideas were introduced. Focusing on that view, an important assumption which might be inferred is the need for addressing the difficult abstract ideas such as those related to the energy concept in a motivating and understandable way for the majority of the students, that is the middle and the low achievers; and, according to the above report, simulations and in more general visual representations seem to serve this goal. Furthermore, it might be claimed in addition to the teacher's views that, not the simulations alone but their combination to the Interactive/Dialogic approach applied motivated the students to put an interest on the lessons which resulted in the improvement in their learning.

Additionally, in another part of the interview the teacher expressed the following:

> *R:* I must say that I was particularly impressed by the fact that, some students showed an interest about physics lessons when they had never been interested in before. A group of students, about 4-5, who used to be completely indifferent showed to be interested, to ask questions, that was something positive.

With the above statement, the teacher seemed to be even more enthusiastic about the positive attitude and the increased interest on the physics lessons showed by some low achievement students. Furthermore, this statement seems to advocate for all the above discussion.

In the following, the teacher asked about the high achievement students' attitudes towards the 'new' approach. Her views were as follows:

> *I:* Ok. So, you noticed a significant improvement among the low and middle achievers.
>
> *R:* Yes, an improvement among those students. High achievers have an excellent achievement with one way or the other.

> *I:* Even though, did you notice any increase in their interest or a contribution in acquiring a deeper understanding …
>
> *R:* To their interest yes, they showed more interested except the student who had some minimum knowledge on energy from GCSE lessons out from public school, that one did not paid much attention but the rest were positive.

Thus, the teacher reported an increased interest among high achievement students also. At this point, the interviewer proceeded to further probing as follows.

> *I:* Do you believe that the material contributed in acquiring a deeper understanding on energy or didn't you notice any difference?
>
> *R:* Yes, I noticed a difference, I compare the high achievers of other classes in which I didn't use the material, the way of approaching the concept was rather superficial and thus, they did not had an integrated consideration on energy, not an integrated picture, whereas I believe that these students have a more integrated picture of energy.

Whereas for middle and low achievement students the teacher reported an improvement in their learning, for high achievement students a better understanding of the energy concept compared to high achievement students taught through 'normal' teaching by herself.

Another issue raised by the teacher concerned the students' attitudes towards the handouts corresponding to each one of the lessons of the teaching sequence. She expressed as follows:

> *R:* Simply, the students are not used in studying that kind of notes, I mean that they prefer just very brief … brief notes, they don't want to study much, that's why some of them complained that the handouts were long. But on the other hand, some others found them very helpful.
>
> ………………………

> *R* ...but to some others ... they didn't like the fact that they had to study the detailed handouts. A part of lazy students, who do not like studying at all, only reacted rather negatively.

In the above part, the teacher reported two diametrical different attitudes towards the handouts: the positive one according to which some students considered them as helpful with the energy ideas be presented in some detail and the negative one according to which some students complained about the fact that the handouts were detailed and thus thought to be too extensive. However, it should be noted that, none of the handouts exceeds the four pages; but what the students were used to was to memorize only the definitions and the mathematical formulae dictated by the teacher during lecturing and never study from their book.

6.5.4 ASPECTS OF THE TEACHING SEQUENCE ON WHICH SOME MORE EMPHASIS SHOULD BE PLACED BY THE TEACHER

The teacher also commented on specific issues included in the teaching material which had not been completely understood by the students as follows:

> *R:* They say for example that it goes to the internal store of the car, if it is about a moving car which stops in the end. They don't specify. That is, they forget all the other parts of the system, the surrounding air, the ground, they just say that it goes to the internal store and they don't specify where this internal store is found.
>
> *I:* So, do you think that we spot a difficulty in understanding the concept of a system?
>
> *R:* Yes, maybe. I think that I maybe didn't emphasize enough on that matter.

The teacher expressed the view that she should emphasize on the idea of a system in order understanding problems concerning the places at which the degraded energy is stored. The idea of a system is one of the introductory ideas and a non-related to the energy concept. Thus, is important role in the analysis of a physical process in terms of energy might not be appreciated in a first place by a teacher who teaches the instructional material for a first time.

In the following, the teacher raised another issue related to that of the idea of a system.

> *R:* Another thing on which I would like to comment on regarding energy is that, whenever we present an example, whenever work on a question about energy, we should emphasize that we are talking about the energy of the system and not about the energy of an object only. For example, when we pose a question about the amount of energy at the start compared to that in the end, we should emphasize that we are talking about the energy of the system, otherwise the students consider that we are talking about the object and answer that it is less of course.
>
> *I:* Fine.
>
> *R:* … because it is transferred from the object and stored somewhere else. Whenever we ask about energy at the start and in the end, about the relation between them, we should emphasize on the fact that we ask about the energy of the system.
>
> *I:* Fine. That is, do you believe that some students who respond sometimes, no there isn't any energy in the end …
>
> *R:* … are talking about the object only, about one single object and not about the system.

The above part suggests lack of understanding of energy as a property of a system by the students as it is proposed in the introductory first lesson of the teaching sequence. Thus, emphasis should be placed on that idea rather on emphasizing in each single question that we ask about the energy of the system and not about the energy of a particular part of it as suggested by the teacher. Again, the importance of the introductory idea of energy as a property of systems might not be appreciated to the extent that it should by a teacher who teaches the instructional material for a first time.

6.5. 5 THE TEACHER'S OVERALL VIEW ABOUT THE TEACHING SEQUENCE

In an overall evaluation of the teaching sequence, the teacher stated the following:

> *I:* Do you think that it might be useful to use it in the future?
>
> *R:* Certainly yes, I believe that after some improvements it will be very good.
>
> ....

> *I:* Anna, do you have something else in mind, as the teacher who had been involved and taught it for a first time?
>
> *R:* Yes, it is an innovative approach, that is, I feel that it was more interesting for me to teach it.
>
> ....
>
> *I:* Anything else?
>
> *R:* Ok. I believe that the material, after a few improvements will become a very effective one for the instruction of energy.

The teacher's overall views might be considered as encouraging about the research-informed teaching sequence for teaching the energy concept.

6.6 SUMMARY-DISCUSSION

In the first part of this chapter, the cases of four experimental students were examined. Two of them were low achievers and the other two high achievers. Three of the students initially expressed energy views within an alternative context whereas the fourth according to the 'forms' approach.

The focus of each student's case was placed on their energy learning profile, namely, on the detailed account of their developing understanding of the concept of energy taught through the research-informed sequence. This aimed to reveal the way in which learning of energy was taking place over an extended timeline such as the proposed ten-lesson sequence.

The study of the energy learning profiles suggested a progressive shift in their understanding towards the proposed research-informed approach. For all four students, the learning outcome was an understanding of the concept of energy; for low achievers, through a slower learning procedure due to difficulties in grasping certain ideas such as those of conservation and degradation of energy, which persisted for some time; for high achievers, through a quicker learning procedure and with fewer difficulties in understanding the introduced ideas.

The insights summarized above allow for an answer to the third research question which is: The understandings of the concept of energy of the students of a small sub-group were developed in a meaningful way through the lessons of the research-informed approach.

The answer to the third research question provides strong evidence for the effectiveness of the proposed research-informed teaching sequence in promoting conceptual understanding of energy. This is in full accord with the findings revealed from analysis presented and discussed in the previous chapter and both confirm and strengthen the answer to the second research question.

Turning to the second part of the chapter, this includes a thematic presentation of the experimental teacher views on the teaching through the research-informed sequence. These views are considered and discussed in some detail in Chapter 7-Summary of Findings and Discussion.

CHAPTER 7-SUMMARY OF FINDINGS AND DISCUSSION

In this last chapter, the key findings which provided answers to the three research questions of the study carried out in this doctoral thesis are summarized and examined from a critical point of view.

Then, the strengths and the weaknesses of the research-informed teaching sequence, as these revealed from the findings and the experimental teacher views are presented and critically discussed.

This is followed by a summary of the considerations made in establishing conditions of equal treatment between the experimental and the comparison group. Furthermore, the weaknesses in rigorous control over specific variables of the research and their implications on the findings are discussed.

The chapter concludes with a discussion on the implications of the study on energy education, both in a Cyprus and an international context and recommendations for further study are formulated.

7.0 INTRODUCTION

Much interest has been placed on energy education over the past three decades and this has continued right up until the present. The numerous studies found in the international science education literature have mainly focused on the investigation of students' interpretations about energy and on the formulation of theoretical frameworks aimed at the development of effective teaching approaches for energy.

The earlier review (Chapter 2) of the studies investigating students' interpretations about energy revealed a set of alternative interpretations which proved to be common across a wide range of ages and nationalities. These alternative interpretations often persist even after formal instruction of energy, with various studies reporting that these were identified among high school students, university students and pre-service primary teachers. Furthermore, the findings of the study carried out in this doctoral thesis provide evidence that Cypriot high school students hold the same alternative interpretations about energy as other students thirty years ago and after they were exposed to formal instruction of the concept in their primary and lower secondary schooling. This suggests that energy education is still in a relatively poor state both nationally, in the Cyprus educational context, and internationally as evidenced in Chapter 2.

In this doctoral thesis, a theoretical framework for teaching energy was formulated with a main aim to promote conceptual understanding of the concept of energy. On the grounds of this theoretical framework, an innovative research-informed teaching approach was developed and implemented within a Cyprus high school context. The findings of the research carried out strongly point to the effectiveness of this innovative teaching approach. Unlike other teaching approaches found in the international science education literature (Chapter 2) or currently in practice, such as in the Cyprus National Curriculum for Physics, the proposed research-informed teaching approach includes three key elements: it is based on a theoretical framework in which the energy ideas introduced are consistent with the current scientific views for energy; the concept of energy is introduced through an integrated theoretical framework; it is accessible to students. As evidenced by the findings of this study, these key elements serve well the main aim of the teaching approach, namely, to promote conceptual understanding of the concept of energy.

The theoretical framework that forms the basis of the research-informed teaching approach was developed drawing on the ideas proposed within the SPT11-14 project (2006, Lawrence, 2007). In examining this SPT energy model from a literature review perspective, it can be seen that in its turn, this has built on preceding ideas: energy is considered as an abstract in nature, mathematical quantity as defined by Feynman (1963, p.4-1); changes observed in a system, as a physical process takes place in it, can be visually represented with abstract representations, as proposed by Boohan and Ogborn (1996b); the transfer of energy from an initial to a final stage of a system can be represented quantitatively with a Sankey diagram, as proposed by Millar (2005).

As presented in Chapter 4, the SPT energy model was underwent considerable developments and innovations aiming the development of a theoretical framework which could consist of the basis on which an effective teaching approach for promoting conceptual understanding of the concept of energy be constructed. In particular, these included the elimination, modification and substitution of a series of elements proposed which were considered as sources of creating misconceptions, confusion or of difficulty in grasping the indented knowledge. The most important developments and innovations underwent are: the visual representations of the energy stores as tanks emptying and filling with energy were eliminated since they were considered as entailing a great risk in considering energy as a kind of liquid and thus as substance rather than abstract in nature. Instead, these were substituted by a simple abstract bar notation and the changes in the amount of energy in an energy store are represented with an increase or a decrease of the height of the bar; the visual representations of the various energy transfer pathways were eliminated since they were considered as not promoting understanding of the mechanism or process involved in the transfer of energy along the specific pathway visualized, rather that they entail the risk of confusion to students. Instead, these were substituted by the simple abstract notation of an arrow with the thickness of the arrow to visualize the amount of energy being transferred from one energy store to another; definitions were formulated for the introduction of both the various kinds of energy stores and energy transfer pathways along with the corresponding visual representations. It was considered that the use of both verbal and visual representations provide a coherent way of teaching these ideas rather than using the visual representations alone; a physical process occurring in a system is represented with two snapshots, one for the initial and one for the final state of the process instead of a time-changing representation which was considered as confusing and of unnecessary complexity in visualizing a process under study; four kinds of descriptions, namely, the 'problem statement', the 'physical description', the 'energy description' and, the 'mathematical description' are proposed to be used for the analysis of the physical changes occurring in a system rather than using only the 'physical' and the 'energy' description. The addition of these descriptions were considered as necessary in facilitating the full qualitative and quantitative study of a physical process which the physical and the energy descriptions alone cannot do; the Full Sequence Energy Diagram was proposed to be used as a tool for a detailed qualitative and quantitative study and interpretation of all changes which take place in a complex system in terms of energy rather than the use of a Sankey Diagram which includes information only for the initial and the final state of the system under study.

Regarding the energy ideas proposed within the theoretical framework, their use in the development of this innovative research-informed teaching approach provided the opportunity for a timely first evaluation of them with respect to their effectiveness in the instruction of the concept of energy. The interest of this timely first formal evaluation of these ideas focuses on two main issues: first, they propose the instruction of energy according to the current scientific views of the concept, namely, as an abstract in nature entity within the context of Cyprus general compulsory education and not at an advanced physics level through a coherent way using abstract simple visual representations; second, they offer a different approach to teaching energy which could be said that it moves against the current of earlier and recently proposed approaches grounded on the 'forms' tradition (Chapter 2) and maybe challenges them in terms of scientific consistency and effectiveness. Furthermore, these and the strong evidence provided by the findings on the effectiveness of the innovative teaching sequence, reinforces the study's significance as a contribution to energy education.

7.1 A REVIEW OF THE ANSWERS TO THE RESEARCH QUESTIONS IN THE LIGHT OF THE FINDINGS FROM THE STUDY

In this section, the findings which provided answers to the research questions addressed in this doctoral thesis are briefly reviewed and implications due to the answers provided are critically discussed.

7.1.1 FIRST RESEARCH QUESTION: 'WHAT CONCEPTS OF ENERGY ARE USED BY A CYPRIOT COHORT OF UPPER HIGH SCHOOL STUDENTS PRIOR TO TEACHING?'

Findings from analysis of pre-test data clearly suggest that overall there was little understanding of the energy concept among students of both the experimental and the comparison group prior to the teaching intervention. Rather, the ideas expressed by the students fell within an alternative energy context.

In particular, part A of the pre-test revealed that only a very small number of the participant students formulated a kind of energy-based interpretation for the event of the simulation whereas the great majority used force in their interpretations. As discussed in section 2.3, this kind of interpretation falls within the 'activity' model of energy. Concerning the four aspects of the energy concept it was revealed that: (i) there was some reference to an energy store, (ii) there wasn't an understanding of the energy transfer aspect, (iii) there was a very weak understanding of a kind of conservation of energy aspect and, (iv) there was no reference to the degradation of energy aspect among the participant students. Furthermore, the comparative study of the experimental and the comparison group results suggest very little difference between the two groups: (i) in the number of students who formulated an energy-based interpretation of the event of the simulation and, (ii) in the students' understanding of each of the four aspects of the energy concept.

From part B, findings revealed that the most frequently used alternative framework was the ‘activity’ model of energy; whilst other frequently used alternative models were the ‘depository’ and the ‘anthropocentric’ models respectively. Moreover, the comparative study of the results of the experimental and the comparison group revealed that each of the most frequently used alternative models appear with about the same frequency among students in the two groups.

The answer to the first research question formulated in the first paragraph of this section raises serious considerations concerning the effectiveness of the current Cyprus National Curriculum in teaching and learning of energy. As discussed in section 4.4, prior to the first grade of upper secondary school under study, energy is introduced first in the sixth grade of primary school and then in the second grade of lower secondary school. Energy curricula corresponding to these grades include the study of the changes occurring in various physical systems in terms of energy and through the ‘forms’ approach; this prerequisite knowledge of the key energy ideas which are included in the ‘forms’ approach. However, the findings from pre-test data analysis clearly suggested very limited knowledge of the scientific concept of energy and the majority of the students expressing alternative interpretations about energy. Furthermore, it could be argued that these findings would correspond to students of no previous formal energy teaching rather than been introduced with the energy concept both in primary and secondary schooling.

The above discussion advocate to the ascertainment expressed in section 4.5 that the current Cyprus National Curriculum for energy is not effective in promoting conceptual understanding of the concept of energy. Rather, it points to the need for a deep and integrated reconstruction of the curricula of all grades of primary and secondary education in which the teaching of energy is included; this should include the content, the instructional approach and the time devoted to the teaching and learning of energy.

7.1.2 SECOND RESEARCH QUESTION: ‘HOW DO THE CONCEPTIONS AND LEARNING OF THE SUB-COHORT OF CYPRIOT STUDENTS TAUGHT THROUGH THE RESEARCH-INFORMED APPROACH COMPARE WITH THOSE FOLLOWING ‘NORMAL TEACHING’ AFTER INSTRUCTION?’

Findings from analysis of post-test provide strong evidence that overall students in the experimental group acquired a relatively good understanding of the energy ideas after instruction through the research-informed approach whereas there was limited understanding by the students in the comparison group followed 'normal teaching'. These findings strongly underline the effectiveness of the research-informed approach for teaching the energy concept.

Specifically, from part A of the post-test it is revealed that the great majority of the experimental group students formulated a full or a partially full energy description of the event of the simulation whereas only a small number of comparison group students formulated a partially full one. Regarding the store, transfer, conservation and degradation aspects of the energy concept, findings of the comparative study suggest a significantly greater understanding among experimental group students compared to that of comparison group students. Furthermore, comparison of pre and post-experimental stage results suggest a greater improvement in the experimental group students': (i) ability in describing in terms of energy the event of the simulation and, (ii) in understanding each of four energy aspects, compared to that of comparison group students. Moreover, as underlined in Chapter 3 in order post-test bias to the content of the experimental instruction be avoided, much consideration was taken so that the post-test address the conceptual content of the current Cyprus National Curriculum.

Turning to part B of the post-test, findings revealed from each of the two novel physical systems suggest a good understanding, by the experimental students, of the energy ideas taught whereas for comparison group students relatively little understanding. Moreover, the experimental group students showed a good ability in using the energy ideas both qualitatively and quantitatively in these systems whereas for comparison group students, this ability was relatively limited.

In reviewing the experimental group students' responses to all three physical systems comprised in the post-test on each of four energy aspects, they suggest a good understanding and an equally good ability in transferring the acquired knowledge to novel contexts. Furthermore, this kind of testing in new contexts provides strong evidence about the stability and transferability of the results concerning the learning outcome on energy among students of the experimental group.

The answer to the second research question formulated above provide clear and strong evidence that the energy knowledge was acquired in much higher degree through the research-informed teaching sequence than through 'normal teaching'. This brings up the discussion conducted in the previous section concerning the effectiveness of the current energy curriculum in promoting understanding of the concept. Evidence about poor effectiveness is particularly strong in the findings revealed from comparison students' data of the two novel systems included in post-test's part B. This points once again to the need for a deep and integrated reconstruction of the energy curricula within the Cyprus Educational System.

Beyond the comparative study of the effectiveness of the proposed research-informed teaching sequence for energy and the current energy curriculum taught through the usually used approach conducted for answering the second research question, another perspective which might be interesting to be investigated in a future similar research is the degree of energy knowledge retained among the experimental students some time after the completion of the experimental intervention. For the investigation of this perspective, a research question which might be addressed is as follows:

RQ: What are the conceptions about energy of the sub-cohort of Cypriot students taught through the research-informed approach after a time interval of the completion of teaching?

The new research question could be answered after the elaboration of data collected through a late post-test administered to experimental students several weeks after the completion of the experimental intervention. Furthermore, the evidence provided through the answer about the degree of establishment of the acquired energy knowledge could provide in its turn further evidence concerning the effectiveness of the proposed research-informed sequence to teaching and learning the concept of energy.

7.1.3 Third research question: 'How do the understandings of the energy concept, of a small sub-group of students, develop during the lessons of the research-informed approach?'

Insights gained from the study of the energy learning profiles of four experimental students provides strong evidence for the development of a meaningful understanding of the concept of energy taught through the research-informed approach. The energy learning profiles were developed with data from the pre-test, diagnostic probes, interviews and post-test.

Student 1, Nicolas, had previous knowledge of the energy concept which was in accordance with the 'forms' of energy perspective, as his responses on the pre-test questions suggested. Analysis of the responses of the first diagnostic probe, the first interview and the second diagnostic probe questions revealed a *mixed model* in which the student was using in some of his responses, ideas and terminology from the 'forms' of energy approach and in others, ideas from the 'new approach'. The responses to the second interview and the post-test questions suggested a change of approach away from the 'forms' of energy with the student's responses formulated according to the ideas and terminology of the 'new approach'. Furthermore, the student demonstrated a good understanding of the energy ideas introduced and an ability to transfer the acquired knowledge to various different systems both qualitatively and quantitatively.

Student 2, Andria, was a low to middle achievement student with no knowledge of energy prior to the teaching intervention. Rather, as her responses to the pre-test questions suggested, her initial views fell within the 'activity' and the 'product' models. On the questions of the first probe, the student demonstrated an understanding of the store and transfer aspects of energy but no understanding of the conservation and degradation aspects. In addition, her diagrammatic energy description suggested a difficulty in recognizing the different situations of the physical process and representing them accordingly in terms of energy. The student's responses to the questions of the first interview suggested a shift in her energy ideas, focused on the conservation and degradation aspects. On the questions of the second probe, Andria's responses were correct or partially correct and formulated in terms of the energy ideas introduced in the 'new approach'. The student's responses on the questions of the second interview suggested an understanding of all four aspects of energy and also, no difficulty in recognizing the different situations of the physical event nor representing it in terms of energy. Finally, Andria's overall achievement on the post-test's questions suggested an improvement in her understanding of the energy concept compared to her initial 'activity' and 'product' views. Although not all of the student's responses were completely correct, they revealed an underlying understanding of the energy ideas and the terminology introduced in the 'new approach' and the ability to transfer them in considering various different systems.

Student 3, Amalia, was a low achievement student with no previous knowledge of the concept of energy. As her responses to the pre-test questions suggested, her initial views on energy were within the 'activity' model. For the first diagnostic probe, her responses suggested an understanding of the store and transfer aspect of energy and little understanding of the conservation and degradation aspects. Furthermore, they suggested a difficulty in linking her energy description to the appropriate parts of the event. The student's responses to the questions of the first interview, the consequent second probe and the second interview revealed a progressive shift in her understanding to the conservation and degradation aspect. Also, the student did not seem to find difficulty in linking her energy description to the appropriate parts of the event. Amalia's responses to the post-test's questions suggested understanding of the energy ideas introduced, though some difficulty in applying the conservation principle in new context and furthermore a difficulty in applying the energy ideas quantitatively.

Student 4, Andreas, was a high achievement student with no knowledge of the energy concept prior to teaching intervention. Rather, his initial views of energy were within the 'activity' and the 'product' models. The student's responses on the questions of the first interview suggested a significant improvement in his understanding of energy compared to that at pre-test. The student seemed to abandon his force-based initial views and fully adjust to the ideas and terminology of the 'new approach'. However, some difficulty in his understanding concerning the transfer pathways to the internal store was demonstrated. For the questions of the second interview, Andrea's responses suggested a shift in his understanding on all the energy aspects. Finally, the student's responses on all the post-test questions suggest a good understanding of the energy concept and the ability to transfer the acquired knowledge to various systems both qualitatively and quantitatively. Some confusion was demonstrated regarding the mechanical working and heating pathways in the case of the energy transfer to the internal store in the process of the degradation of energy.

7.1.4 Issues arising from the case studies

In general the cases point to the way in which learning takes place over an extented timeline. Three of the students initially expressed energy views within an alternative context whereas the fourth according to the 'forms' approach. This detailed study of learning revealed a progressive shift in their understanding towards the 'new approach', maybe including 'mixed models' and difficulty to grasp certain ideas which persisted for some time. For all, the learning outcome was an understanding of the concept of energy which for high achievers was reached through a quicker learning procedure whereas for low achievers through a slower one.

This kind of discussion sends a message for design of teaching approaches which is, the need for opportunities to revisit ideas. Teaching approaches should include activities which would allow the alteration between the introduction of new ideas and the discussion and further elaboration of ideas already introduced. Through this teaching and learning procedure, new ideas are constructed and established.

Cases also provided the opportunity for gaining insights into key points of difficulty. For example, they revealed a difficulty in grasping the ideas of conservation and degradation among the two low achievement students. This, points to a need for emphasis to be placed on those ideas for which difficulties are identified when teaching.

The case studies conducted consist of a longitudinal study of the process of energy learning through the research-informed sequence; thus, the insights gained concern energy knowledge acquisition. A further perspective which might be interesting to be studied concerns energy knowledge retention. This perspective could be studied with the longitudinal study be conducted within an extended time interval which would allow for a late interview. The late interview could be conducted a few weeks after the completion of the experimental intervention. Furthermore, the findings revealed from the analysis of the late interview could be used for the formulation of an answer to the new research question proposed in the previous section.

A perspective which was studied to a limited extent and which might be interesting to be studied in more depth concerns the students' attitudes towards the research-informed approach. The students of whom the cases set up expressed spontaneously at various instances of informal conversations with the researcher and the experimental teacher their views on the 'new approach', which were positive, and were included in the cases. It might be interesting that these be collected, elaborated and studied in a more formal and systematic way; students, as being the recipients of the innovative teaching approach for energy could provide valuable information on features of the teaching approach, such as the degree of considering it as accessible, meaningful and enjoyable, which could be considered in increasing its effectiveness. One way in collecting this kind of data might be through a set of questions in a second part of the interview protocols; another way might be through a short written questionnaire.

7.2 STRENGTHS OF THE INNOVATIVE RESEARCH-INFORMED TEACHING APPROACH

In this section, the evidenced effectiveness of the research-informed teaching sequence is examined from a critical point of view seeking to foreground the strengths of the approach taken. These are presented and discussed as follows.

7.2.1 THEORETICAL FRAMEWORK

As discussed in section 4.7, the theoretical framework on which the teaching approach for energy was developed, was formulated to fulfil four prerequisites according to which instructional approach should : (i) be consistent, that is, the way of presenting the concept of energy should be valid according to the prevailing scientific beliefs, (ii) be coherent, meaning that the ideas are introduced and expressed in an explicit way, (iii) be generalizable, that is, the same ideas presented and expressed can be applied in a variety of different systems and, (iv) enable the full quantitative description of the concept. The formulation of the theoretical framework on the grounds of the four prerequisites set the basis for an effective innovative teaching approach which, as the evidence from the findings of the research indicates, serves the crucial goal of promoting conceptual understanding of the energy concept.

The proposed teaching approach was designed to promote the following key features of its theoretical framework:

- it allows for the introduction of the concept of energy in a scientifically consistent way. As it is defined, energy is an abstract in nature, mathematical quantity, a property of systems. Energy is related to four key aspects, that of store, transfer, conservation and degradation.
- it allows for the definition of energy ideas such as 'mechanical working', 'light', 'sound' and 'heating' in a scientifically consistent way as mechanisms or processes of energy transfer rather than as 'forms' of energy;
- it allows the introduction of the concept of energy in a way which is designed to promote the meaningful understanding of students through the use of simple abstract visual representations which, strengthen the consideration of energy as an abstract quantity;

- it allows for the introduction and the development of the concept of energy from an integrated and not fragmented perspective. This in turn, supports generalizing the use of the energy ideas for the interpretation of physical events in a variety of systems, including more complicated ones;
- it allows for the full quantitative treatment of the concept of energy. The qualitative development of the concept with the introduction of all four energy aspects allows for full quantitative treatment in the analysis of energy problems. An example is presented in section 4.8.

7.2.2 STUDENT LEARNING

The second of two key features of the teaching approach, which could be considered the most important, is its accessibility to students. The energy ideas are introduced in a motivating and understandable way to the students through the combined use of computer simulations, visual representations and opportunities for discussion. In that way, the intended learning process involves two stages: in the first stage, a physical event which takes place in a system in the physical world is studied through a simulation. In the second stage, the physical event is interpreted scientifically in terms of the abstract physical quantity energy, through the use of visual representations. In their turn, the visual representations proposed contribute to the accessibility of the teaching approach because they are abstract and thus leave little space for the creation of misconceptions concerning the nature of energy (such as energy having a real substantial form). The visual representations are very simple to draw by the students, a rectangle to represent the energy stores and an arrow for the transfer pathways. The change in height of the rectangles and in the thickness of the arrows are clearly and easily associated with the amount of energy stored or transferred respectively thus supporting learning.

The contribution of the combined use of visual means and visual representations in the learning of the energy ideas was underlined by the experimental students interviewed as well as the experimental teacher. All four students made positive comments, as discussed earlier in the case studies (Chapter 6). As one of the high achievement students stated: '... the use of visual representations to represent the energy stores and transfer pathways, computer simulations and images of systems observed in the real world, made the lessons more exciting and their content more comprehensive' whereas a low achievement student commented that they: 'help low achievers like myself to understand physics'. In her turn the experimental teacher commented positively: 'Yes, if visual means and visual representations were not used in the teaching procedure, they might not succeed in understanding some things'.

Another strong contribution to the learning of the energy ideas is made by the application of the communicative approach. My view is that the learning outcomes would not be so successful through the use of computer simulations and visual representations alone and with the teacher in a presentational mode of them. The use of both kinds of visual means can become effective in addressing a specific piece of scientific knowledge if it is combined with opportunities for the students to express views and conduct discussions on possible interpretations of what is visualized and; with opportunities for the teacher to draw on the views expressed by the students seeking to present the scientific point of view. As discussed in section 4.8, communicative approach relates to teaching purposes (Mortimer and Scott, 2003); among the four classes of communicative approach, the interactive/dialogic and the non interactive/dialogic seem to play a key role in both stages of the learning process described in the first paragraph of this section.

In the first stage, the interactive/dialogic approach allows for discussion between students in which there is an exchange of views about the physical event observed in the simulation. In the second stage, it allows for a discussion of the different interpretations expressed by the students about the physical event of the simulation. The teacher, through a non interactive/dialogic approach reviews the students' views/interpretations and goes on to present the scientifically consistent model with a more authoritative approach. In this way, conceptual understanding of the energy ideas is enhanced through constructive dialogic classroom talk between the students and the students and the teacher as a precursor to the introduction of the physics model.

At this point it has to be noted that the experimental teacher expressed positive views about the use of different communicative approaches in her interview. She particularly focused on the contribution of interactive/dialogic approach and expressed the view that this should be applied in a more systematic basis in the instruction of physics stating that: 'I believe that the students are not very familiar with that way but I think that they are quite good, that they should progressively get used to that way of teaching, especially in interacting with each other'.

Evidence from post-test data analysis and the experimental teacher interview suggest that the teaching approach, involving discussion and visual representations, was particularly motivating and effective among the low and middle achievement students. As the teacher stated:

> 'I believe that the material is very good, especially the simulations included in the first lessons. I believe that they were very good and succeeded in sparking some students' interest who I didn't expect to be interested. The increased interest due to the simulations was much more obvious among students of low and middle achievement and I noticed a significant improvement in those students …'.

This learning outcome is associated with the accessibility of the teaching approach: physical events observed in the real world are linked with the abstract energy ideas through visualization and the simple consideration of energy stores and transfer pathways. This approach seems to be particularly motivating and understandable among the lower achieving majority of students, and furthermore, it could be considered as a real strength of it. High achievement students would most probably achieve the same outcome through a different, more abstract approach. As the teacher remarked: 'Yes, an improvement among those students. High achievers have an excellent achievement with one way or the other'.

Another element which could be considered as strength of the proposed teaching sequence in terms of learning is the order with which concepts are introduced and treated. In the first three lessons, the terminology and the energy ideas are introduced and treated qualitatively. In that way, the students are introduced to the theoretical framework of the concept of energy. In the following seven lessons, the energy ideas are reviewed in more depth qualitatively and treated quantitatively. Thus, the students benefit from a more advanced qualitative study of the energy ideas which is completed with their quantitative applications. Furthermore, the experimental teacher commented positively on the order of presenting the energy ideas.

7.2.3 TEACHING

Looking at the research-informed teaching sequence for energy from a teaching perspective, it could be characterized as being challenging. The teacher is confronted with a new approach which proposes the teaching of energy through a theoretical framework developed according to currently accepted scientific views as an abstract mathematical quantity and away from the usual 'forms' of energy approach. Unlike this traditional 'forms' of energy approach in which the aspect of transformation dominates and the other energy aspects are sub-presented, in the new approach energy is conceptualized through four aspects of equal significance, that of store, transfer, conservation and degradation.

Another element to make the proposed teaching approach challenging is that it involves a wider range of teaching approaches. The explicit application of the communicative approach leaves space for more dialogic interaction both between the students and between the teacher and the students. As suggested by the international research literature (see, for example: Leach, Scott, Ametller, Hind and Lewis, 2006), these more dialogic approaches have the potential to support meaningful learning of concepts as points of view are talked through in an open-handed way.

The proposed teaching sequence could also be characterized as enjoyable to teach. This includes a variety of activities which allows the teacher the use of different visual means such as computer simulations, images and short PowerPoint presentations and worksheets. In a final comment about practicing the research-informed teaching approach, the experimental teacher stated the following: 'Yes, it is an innovative approach, that is, I feel that it was more interesting for me to teach it'.

7.3 WEAKNESSES OF THE INNOVATIVE RESEARCH-INFORMED TEACHING APPROACH

In this section, the weaknesses of the research-informed teaching sequence, as identified in its implementation, are presented and discussed.

7.3.1 CONTENT

One weakness identified by the experimental teacher concerns the way of introducing the idea of chemical store in both the relevant simulation and the handout. The simulation presents two kinds of reactants (atoms) to combine and formulate a new product (a new kind of molecule). As the chemical reaction occurs, that is, as the formulation of the product occurs, the energy of the chemical store of the system reactant-reactant increases. Correspondingly, a chemical store is defined in the handout as follows: 'when a chemical reaction between two substances occurs (for example fuel and oxygen), there is energy in a chemical store of the system reactant-reactant, due to the kinds of bonds between the atoms or molecules which constitute the reactants'. The students failed to identify a chemical store in the system food-oxygen in humans in systems set out in the relevant worksheet. Only after discussing these with the teacher, was the presence of a chemical store understood. This difficulty seems to be rooted in the fact that both the definition and the simulation are strictly referred to a chemical store when a typical chemical reaction in laboratory conditions takes place. As the teacher suggests, chemical store could be presented in a more understandable way, if more worked examples are included in the handout in which the case of a chemical store in the system food-oxygen is discussed.

Another weakness of the same nature was identified for an internal store. The relevant simulation presents an internal store in the case of a gas. In particular, a gas is heated up from room temperature. As the temperature of the gas increases, the energy of the kinetic store of the particles which constitute the gas increases resulting in an increase of the energy of its internal store. Correspondingly, an internal store is defined in the handout as follows: 'a solid, a liquid or a gas has energy in an internal store. Internal store consists of two parts: the energy because of the continuous motion (kinetic store) of the particles (atoms, molecules) from which an object or a substance is made up and, the energy of the chemical bonds between the atoms or the molecules'. As the experimental teacher reports in her interview, students confused the content of this simulation with that of chemical store. She remarks that this confusion might be due to the fact that both simulations present processes in which particles take part. The students also failed to identify internal store in the systems set out in the worksheet and only after discussion was this understood. Furthermore, the teacher suggests that the relevant part in the handout should be enriched with more worked examples in which various cases of internal stores are discussed.

Further weaknesses concerning the way of introducing the energy ideas were identified in relation to the cases of heating and sound transfer pathways respectively. As the experimental teacher noted in her interview, students showed at first a difficulty in identifying the energy transfer along a heating or a sound pathway in the systems in the relevant worksheet. As in the case of chemical and internal stores, heating and sound pathways were understood by the students after discussing the energy transfer in the systems under study. Moreover, she remarked that whereas mechanical working is presented in handouts in detail, both qualitatively and quantitatively, heating and sound are introduced through a single definition. She suggested that worked examples accompany the introduction of each of the two pathways in the relevant handout.

7.3.2 TEACHING

A weakness of fundamental importance was identified in terms of teaching the ideas of a system and of energy as a property of systems. The idea of a system is introduced in the first lesson of the teaching sequence. Although an introductory one, understanding of the idea of a system is essential in supporting understanding of all four aspects of the concept of energy and especially that of degradation. In introducing the idea of a system, not much emphasis was placed by the experimental teacher, nor was there much discussion of the relevant worksheet questions. Many students did not fully understand it resulting in a failure to identify all the parts of a system and in particular those of the surrounding air and the ground. In turn, this resulted in failing to identify all the places in which energy is found in internal stores after being degraded. Furthermore, as the experimental teacher remarked:

> 'They say for example that it goes to the internal store of the car, if it is about a moving car which stops in the end. They don't specify. That is, they forget all the other parts of the system, the surrounding air, the ground, they just say that it goes to the internal store and they don't specify where this internal store is found'.

In order the difficulty in grasping the idea of a system by the students due to insufficient teaching is overcome, it might be useful that a reference be included in a teacher notes handbook.

The introduction of the idea of a system is followed by that of energy as a property of systems. Not much attention was placed on the idea of a system in the teaching material and then by the teacher resulting in a less full understanding by many students. Failure in establishing a full understanding of the idea resulted in a difficulty in applying the conservation principle; the students tended to consider the conservation of the energy of an individual part of a system rather than that of the whole system. This difficulty was commented on by the teacher as follows:

> 'Another thing on which I would like to comment on regarding energy is that whenever we present an example, whenever we work on a question about energy, we should emphasize that we are talking about the energy of the system and not about the energy of an object alone. For example, when we pose a question about the amount of energy at the start compared to that in the end, we should emphasize that we are talking about the energy of the system, otherwise the students consider that we are talking about the object and answer that it is less of course'.

This points to the need for a more attentive and focused way of presenting the idea of energy as a property of systems both in scheme and in the teaching. Regarding the teaching, the teacher's attention on the importance of grasping this idea by the students could be drawn with a reference in the teacher notes handbook.

The fact that within the context of the research-informed teaching sequence a first attempt at dialogic practices was made could be considered as another weakness (or at least a challenge) in terms of teaching. On the experimental teacher's part, this was the first attempt at teaching physics through an approach other than the usually used direct authoritative teaching. Although less familiar and practiced, it has to be noted that she succeeded in applying all four classes of communicative approach as defined in the lesson plans to a good degree. Equally, for the experimental students, this was the first time in which they were taught physics through a teaching approach other than the authoritative one. At the very beginning of the teaching intervention, the students did not seem keen to participate in classroom talk whenever an interactive/dialogic approach was encouraged. In the following lessons, as the students were getting familiar with this kind of teaching, they seemed much more interested and able to enjoy participating in classroom discussions.

As discussed earlier, the findings of the study carried out enhanced a strong contribution of the use of dialogic practices in the teaching and learning of energy. This dictates the need for taking two actions: to use dialogic practices on a more systematic basis in teaching not only the concept of energy but also other topics of physics. According to the second one, there is a need for practicing the use of all four communicative approaches (and especially the dialogic ones) by both the physics teacher and students. Furthermore, learning results might be enhanced still more if students become familiar and practiced in the learning of physics through varied communicative approaches from younger ages and before high school.

7.3.3 TIME ALLOCATION ACROSS THE TEACHING SEQUENCE

One issue raised by the experimental teacher as need consideration in various parts of her interview, concerned the time devoted to certain parts of the teaching sequence. The teacher's comments were initially focused on the first lesson. She expressed the view that its content should be introduced in two rather than one lesson. The main argument for this suggestion was that there should be some time available in which the key ideas introduced can be discussed in the classroom through examples which would help students to put them together and thus enable them to formulate complete energy descriptions. In adding to the teacher's view, I would suggest that some extra time is needed in the second lesson in order more examples on Sankey and Full Sequence Energy Diagrams of systems be analyzed.

The teacher raised the issue of time also for the lessons in which the mechanical store idea and the conservation of mechanical store theorem are introduced. She expressed the view that more time is needed for the discussion of examples of systems in which the conditional theorem of conservation of mechanical store is not valid due to degradation of energy.

At this point it should be noted that much consideration was placed on the issue of time devoted for each part of the teaching sequence by the researcher. The points raised by the teacher were rather expected since decisions about time were made after taking into account the content of the innovative theoretical framework, the content of the current curriculum and the school time available. Furthermore, the issue of time raised links with the findings from the case studies which indicate that learning takes place over an extended time line. From my point of view, if the limitations mentioned earlier did not exist, I would extend the core lessons from three to five. In this way, satisfactory time would be available for both the introduction of the key energy ideas and for revisiting them through a range of examples of physical systems which might be gradually more advanced. Rather, the two lessons on the mechanical working-kinetic store theorem and the conservation of mechanical store theorem could be removed from the teaching sequence. These, could be very well discussed within the context of the general conservation of energy principle since the first consists a simple application of it which and thus does not actually requires special treatment and the second consists a conditional application of it, namely, it is valid only in those ideal cases in which no degradation of energy takes place during the upwards or downwards movement of an object.

7.4 DESIGN EXPERIMENT-FIRST CYCLE

The educational 'experiment' carried out in this doctoral thesis is a quasi-experiment. Within the field of educational research, there are voices which express their scepticism about quasi-experiments and their outcomes. This scepticism is rooted in the difficulties and furthermore the limitations of conducting an educational research in the complex and changeable environment of natural educational settings which in their turn, affect on the validity and generalizability of the outcomes. A key limitation of a quasi-experiment relates to the lack of rigorous experimental control; variables can be isolated, controlled and manipulated but only a partial control can be exercised over experimental variables. However, it is my view that this should not be considered as the reason for a claim that quasi-experiments should not be conducted or that their outcomes are not valuable and useful; these are well balanced by the benefit of the richness and reality of their outcomes which a 'true' experiment (Campbell and Stanley, 1963), namely, an experiment conducted in the equivalent of laboratory and thus artificial environment cannot provide. Furthermore, quasi-experiments should be conducted and when conducted the maximum control should be pursued through a careful design and implementation; outcomes should be interpreted taking into consideration the particular conditions existed during implementation and; outcomes be tested in consequent experimental cycles.

Another key limitation of the quasi-experiment relates to the lack of randomization of the participant students. Random allocation of the students in the experimental and the comparison group is not feasible in real educational settings; rather, intact classes hold the role of the experimental and the comparison group with their normal teachers acting as experimental and comparison teacher respectively. A further limitation of the study concerns the fact that it was carried out in one single urban high school.

The lack of randomization of the participant students and the fact that the quasi-experiment carried out in one single high school potentially produces a problem related to the generalizability of the findings. On the other hand it could be argued that the great majority of Cypriot students follow public education. Cyprus public schools are considered as of about the same educational level, since no considerable fluctuations in the students' overall achievement among schools is reported. The first grade high school classes are mixed ability classes in which, as discussed in section 3.4, the students are allocated with the use of the stratified random allocation on achievement (Slavin, 1984, p.23). Although some fluctuations in the overall students' achievement might be identified among mixed ability classes, these are not considerable. It could also be added that evidence about the equivalence of the mixed ability intact classes acting as the experimental and the comparison group is provided by the comparative results of the initial ideas of the students on energy revealed by the pre-test. Furthermore, findings concerning the students' initial ideas on energy are linked with international literature reporting on them.

Taking into account the previous discussion it could be argued that findings of the study carried out in this doctoral thesis could be generalizable up to the extent of a Cyprus context. The truth of this argument could be examined and verified or rejected through further research with the participation of a greater number of students in many intact classes and in various high schools. However, even though the sample was small it is nonetheless plausible that a larger sample might yield broadly similar results. Furthermore, in my view the outcome of such an extented research would verify the findings of the study for the reasons discussed earlier.

One issue which appears in the research methods literature concerns the outcome of the post-test data analysis: the effect of pre-testing on the post-test results (see, for example: Cohen, Manion and Morrison, 2007). According to this, post-test results turn out higher than expected due to the fact that students are familiar with the tasks in the post-test because of pre-testing. The possible effect of pre-testing on the post-test results was examined by comparing the experimental students' results to the questions of part A, which is the same as pre-test part A, with those from the corresponding questions of post-test part B. Findings from comparison suggest a good understanding on each of four aspects of the energy concept and that results are stable. Furthermore, findings from this kind of comparison provide evidence that there is no effect on experimental students' results because of pre-testing. The results on the questions of post-test part B referring to new context revealed as high, and in some cases higher than those, of the corresponding questions of post-test part A referring to the known context of pre-test part A (section 5.2.8).

The quasi-experiment carried out in this doctoral thesis was carefully designed and much attention was placed on the implementation of the design developed. Since it was focusing on the study of the effectiveness of an innovative research-informed approach aiming to promote conceptual understanding of energy in comparison to existing approach, considerable consideration was placed on the establishment of conditions of equal treatment between the classes acted as the experimental and the comparison group respectively. The establishment of equal treatment conditions between the groups consists a key requirement in order that possible claims about learning outcomes are valid in terms of research methods literature. A few of the considerations made are already discussed in chapters 3, 4 and 5 and summarized in the following whereas others are presented and discussed.

These concerned the issues:

Selection of teachers

The two teachers acted as the experimental and the comparison group teachers were selected among the six teachers consisting the physics teaching team of the school. The teachers were physics specialists, trained educators, IT skilled, they had the same years in service, they had the same experience in teaching first grade classes and a good record in physics teaching. The matter as to who would act as the experimental and who as the comparison teacher was arranged between the teachers. These were considered as adequate in ensuring the equivalency of the teachers in terms of being skilled and experienced and up to a point, randomly assigned. Furthermore, these were considered as adequate evidence for equal treatment of the experimental and the comparison group in terms of physics teaching.

Selection of intact classes acted as the experimental and the comparison group

The two classes acted as the experimental and the comparison group respectively were selected by the experimental and the comparison teachers among the three first grade classes each of them was teaching. The main criterion used for selecting each particular class was the degree of cooperation between the teachers and the students. The fact that these classes were of mixed ability and thus potentially equivalent was not considered as adequate evidence for their equivalency. Their equivalency was examined in two ways: first, the average overall student achievement in physics was compared and found about the same. As comparison measure, the mean value of the students' grades in each class for the first and second trimester was used. Second, as discussed in previous paragraph, each group's findings revealed from pre-test data analysis concerning the students' pre-instructional interpretations about energy were compared; comparison suggested no difference in the pre-instructional interpretations about energy between experimental and comparison students. The results of these two comparisons were considered as adequate evidence of the equivalency of the classes acted as the experimental and the comparison group.

Time of energy teaching-Energy knowledge taught

According to current curriculum for the first grade of high school, the teaching of energy is allocated in eight lessons and this would be the time for comparison group. Due to specific activities included in the research-informed approach such as the study of simulations and classroom talk between the students and the intervention of a 15-minute and a 20-minute diagnostic probe, the equivalent teaching time for the experimental group was estimated to ten lessons.

Regarding the energy knowledge to be taught, it was decided that the same energy content would be addressed to both groups. Specifically, comparison group would be exposed to current curriculum whereas the experimental group to the research-informed teaching sequence which is a reconstructed version of the curriculum. However, as often happens in naturalistic studies, it became impossible to experimental and comparison teachers to strictly follow the designed schemes; this happened due to unexpected in-school activities such as athletic meetings and competitions. Furthermore, the teaching of energy should be restricted in less time than that defined in the teaching schemes due to school time limitations; review and final exams would follow the teaching of energy according to formally scheduled dates.

For the experimental group the teaching time for each of the first three lessons of the sequence was restricted to 30-35 minutes instead of the 45 of a normal lesson. The time lost corresponded to the time of about a lesson and thus the teaching to experimental group took place in the equivalent of nine instead of ten lessons planned (with the time for the two short probes included). The teacher dealt with the loss of time by restricting the number of worked examples and the time for classroom talk. In that way, she managed to introduce all energy ideas as planned and conclude the lessons. However, analysis of the first interview of the four experimental students conducted right after the first three lessons suggest a difficulty in understanding, less in high achievement and more in low achievement students, of the key ideas of the concept of energy. This difficulty in understanding could be attributed to the loss of teaching time in these lessons which are considered as the core of the teaching sequence since all four key energy ideas and new terminology are introduced and qualitatively elaborated. In particular, the restricted number of worked examples and of classroom talk and thus the restricted qualitative elaboration of the ideas introduced seemed to have a negative effect on the understanding of the experimental students.

For the comparison group, the energy teaching was restricted to six rather than eight lessons. The comparison teacher dealt with the loss of teaching time by choosing to introduce and elaborate qualitatively and quantitatively all the key energy ideas and skip out or omit activities and knowledge which could be considered as of secondary importance in contributing to understanding of energy. Specifically, he introduced Hooke's law to support the introduction of the idea of elastic energy but skipped out the experimental verification of the law by the students and; he omitted the introduction of the mechanical working-kinetic energy theorem, which actually is an application of the general law of conservation of energy. This omission affected on the comparison students' ability in applying the theorem to post-test's part B sub-question (1d) (Appendix B); the majority of the comparison students did not respond to the question whereas those responded failed in reaching a correct answer.

Language of the post-test

The matter of the language in which post-test's questions were formulated was carefully considered since this could create a risk of bias to post-teaching assessment of one of the groups. For part A, no considerations were made since this was the same as that of pre-test's part A. This part's questions were formulated in a simple language in which terminology related to the energy concept was avoided. Attention was focused on part B for which a similar decision was made; conditions of equal treatment were kept with the questions being formulated in a simple language in which terminology used in the 'forms' approach applied to comparison group or the terminology of energy stores and pathways used in the 'new approach' applied to experimental group was avoided.

The findings of the quasi-experiment presented and discussed in chapters 5 and 6 and summarized in previous sections of this chapter, provide clear evidence of the effectiveness of the research-informed sequence to teach the concept of energy. The effectiveness of the proposed innovative sequence is evidenced in two ways: through comparison of experimental students' pre-instructional views on energy to their post-instructional views and; through comparison of the experimental students' post-instructional views on energy to those of comparison students who received 'normal teaching'. However, the evidenced success of teaching energy through the research-informed sequence might be perceived by those who face quasi-experiments with scepticism as '*just* a Hawthorne effect', as Brown (1992, p.163) reported the expressed by a few researchers criticism about the outcomes of her naturalistic research work. In the case of the quasi-experiment carried out, this criticism could be rejected by two key facts: first, the lessons of both the experimental and the comparison class were video recorded; thus, experimental attention was equally placed on both groups. Furthermore, the question which could be posed in turn is, why experimental group's learning outcomes are much greater compared to those of comparison group's while both groups were monitored? Second, as reported in Chapter 4, a few experimental students showed poorer classroom behaviour than was usual in the first three lessons of the sequence because of the presence of the video camera. Due to this fact, the experimental group's learning outcomes after instruction should be lower compared to those of comparison group's; however, findings advocate for the opposite.

7.5 IMPLICATIONS/RECOMMENDATIONS ARISING FROM THIS STUDY

Efforts made over a time of more than three decades in the direction of improving energy education have proved to be not particularly successful, as the earlier critical review of the various international research studies has revealed (Chapter 2). This point towards the need for a focus to be placed on those factors which would enhance the development of innovative teaching approaches to promote the effective instruction of the concept of energy.

Findings from the study carried out in this doctoral thesis provide evidence for a strong association between the effectiveness of the research-informed teaching sequence and its accessibility. The learning process was rendered effective through a motivating and enjoyable introduction to the difficult abstract ideas, using a combination of different visual representations and a wider range of approaches to classroom talk. This creates the need to carefully think through the school science view of energy which is accessible to students over a range of ages. That is, rather than avoiding the early instruction of energy, as is the case in many national curricula, ideas being evidenced as enjoyable and motivating to students could be used for the development of teaching materials to address the concept of energy in younger ages.

Although accessibility is a key feature, this however cannot characterize an effective teaching approach for energy alone. Various instructional proposals from the international science education literature although accessible to students, failed in promoting understanding of energy because of a lack of scientific consistency of their theoretical frameworks which is the case with the forms of energy approach (section 2.10) and of energy as a causal agent (section 2.11). Thus, an effective energy education should introduce a school science view of energy which is consistent with the scientific point of view and not simplified for the sake of accessibility.

A considerable part of international science education literature investigating the students' interpretations about energy, reveals a set of alternative interpretations that students across various ages and nationalities hold prior and often after formal instruction of energy (Chapter 2). These alternative interpretations mainly have their roots in the use of the word 'energy' in everyday language. Everyday uses of energy are not consistent with and are often contradictory to the scientific meaning. This dictates the need for an approach to teaching which would help students move between everyday and scientific views, particularly where the learning demands are high. Furthermore, there is a need for preparing students who can talk both everyday and scientific languages and move easily between them according to context. Thus, SAVE ENERGY campaigns actually means to them SAVE FUELS whereas 'conservation of energy' means that an abstract physical quantity remains the same as a sequence of changes take place in a system when studied from a scientific point of view.

The difference in meanings of energy within an everyday and a scientific context creates a need for a focus on areas of high learning demand. For example, within the everyday context energy 'is consumed', 'disappears' or 'runs out' whereas in a scientific context energy is a physical quantity which can be conserved and degraded.

Furthermore, students should be enabled through energy instruction for an understanding that it is fuels what it 'runs out' and not energy.

According to the current Cyprus National Curriculum for the first grade of upper secondary school in section 4.3, much emphasis is placed on the quantitative treatment of the energy ideas introduced. The findings of the comparison between the results of the experimental and comparison groups participating in this study provide evidence for little understanding of energy among comparison students taught through the quantitative-based approach; they also suggest good understanding of energy among experimental students taught through an approach which is focused on the integrated qualitative introduction of the energy ideas. These findings suggest for the need of energy education to move away from mathematical algorithms to learning for meaning.

In examining the current Cyprus National Curriculum for Physics across primary and secondary, lower and upper education, it seems that the time defined for the instruction of energy constitutes only a very small part of the total teaching time of physics. However, the concept of energy is one of the most fundamental and most difficult scientific concepts with a unifying character. Moreover, apart from its scientific significance, energy holds a crucial role in other technological and socio-economic contexts. These dictate the need for establishing an understanding of the energy concept among students and thus, more time should be devoted to its instruction.

All the above discussion suggests that the establishment of an effective energy education is not an easy goal to be achieved. Working in this direction, different levels of action are needed. First, efforts should be focused on the development of a national curriculum through which the effective instruction of energy would be promoted. This requires restructuring the current national curriculum for energy from primary to the upper secondary classes. Considerations for developments should include both content and time devoted. Focusing on content, developments should firstly take into account all factors, as for example the accessibility and scientific consistency, analyzed earlier in this section. Secondly, this should promote the integrated and not fragmented introduction of the energy ideas through an integrated theoretical framework for teaching energy. Thirdly, the content should promote understanding of the energy concept progressively across classes, starting from the lower ones through qualitative treatment and ending in upper classes through advanced qualitative and quantitative treatment.

Efforts in the direction of improving energy education should also consider the role of teachers. No matter how effective a curriculum is, if teachers are not ready to address it properly, its impact will be limited in relation to teaching and learning. In that sense, there is a need for teachers to be supported in moving away from the usual, very fashionable teaching practices for energy such as the 'forms' of energy approach and the solely authoritative teaching. Teachers should be supported through professional development programmes which encourage an openness to training and an enthusiasm to use innovative teaching approaches. Training should involve being informed about the rationale of the innovative theoretical framework and the use of interactive dialogic teaching approaches through which energy instruction would take place. Furthermore, a third level at which there is a need for action to be taken is in school. Schools should be prepared for an energy education in which instruction makes use of various means. Moreover, physics laboratories should be equipped with all technical appliances which would facilitate the use of these means.

Further research

Within this doctoral thesis, an innovative research-informed teaching sequence for the instruction of the concept of energy was developed, implemented and evaluated. Findings of the study carried out provide evidence about its effectiveness in teaching the concept of energy to Cypriot students aged 15-16 year. Taking encouraging findings as a starting point, the validity of the effectiveness of the teaching sequence could be tested through further research. At a first stage, the teaching sequence could be subjected to certain developments taking into account the weaknesses identified and the suggestions made by the experimental teacher for their improvement. The improved version could be implemented to a larger number of students of the same age group, studying at various high schools, urban and rural, of Cyprus. Furthermore, the proposed approach and sequence for teaching the energy concept could be adapted and trialled in other international contexts.

At a second stage, research could be expanded to students of younger ages with those of upper primary school included. The various ideas used in the research work for high school level could be very well used for the development of innovating teaching approaches tailored to a primary audience. For example, findings revealed from the study carried out, provide evidence about the effectiveness of the research-informed teaching sequence among those with low and middle achievement. The use of simulations presenting carefully selected simple systems and of visual representations to present the energy transfer in the systems as a physical process takes place in them, could be used for teaching the energy concept in primary level. Further research along these lines has the potential to lead to an effective energy education within the context of school science.

Conclusion

This doctoral thesis consists of a cycle of design, development, implementation and evaluation of an innovative teaching approach to teach the fundamental and at the same time difficult concept of energy.

Studies found in the International Science Education Literature reporting on perspectives and methods were critically reviewed. Among the perspectives and methods reviewed, the perspective set out by Leach and Scott drawing upon the concept of learning demand and the ideas proposed within the SPT11-14 project were chosen to consist the grounds on which the research-informed teaching sequence for energy was developed. The teaching sequence was then implemented within a Cyprus high school context.

Evidence from the comparative study carried out suggested little understanding of the energy concept among the experimental and the comparison group students at pre-instructional stage. At post-instructional stage, findings strongly suggested a significantly higher understanding of the energy concept among experimental students taught through the 'new approach' compared to that of comparison students received 'normal teaching'. Furthermore, the study of the experimental students developing understanding of energy strongly suggested a meaningful understanding of the concept. These findings point to the effectiveness of the research-informed teaching sequence in promoting conceptual understanding of the energy concept. Furthermore, these consist encouraging start point for further research towards an effective energy education.

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APPENDIX A
Pre-test questionnaires

Name:..

Class:................................... **Date:**..

Study carefully the simulation. Afterwards, answer the following questions.

1. Describe carefully and in detail what you see happening in the simulation-no explanation needed!

....
....
....
....
....
....

2. (a) For each of the events in the simulation described above: explain as best as you can why they occurred.

....
....
....
....
....
....

(b) At the very BEGINNING of the simulation event, is there any energy?

YES or NO?
Choose one. ☐

If YES, where?

....
....

If NO, why not?

....
....
....

3. Think now about the END of the simulation event, when the ball has stopped moving.

Is there any energy?
YES or NO?
Choose one. ☐

If YES, explain.

....
....
....

If NO, why not?

....
....
....

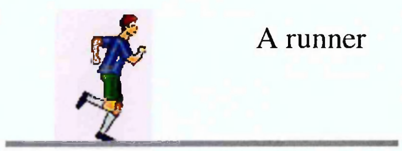
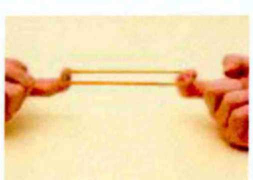
4. What can you say about the amount of energy at the BEGINNING compared with the amount of energy at the END?

....
....
....

5. Finally, describe overall what has happened to the energy of the event from BEGINNING to END.

....
....
....
....
....
....

6. Look at the following. Which of them has energy? Give a brief explanation.

OBJECT	YES/NO	EXPLANATION
1.  A moving car		
2.  A battery		
3.  A runner		
4.  A book on a shelf		
5.  A barrel of petrol		
6.  A stretched elastic band		

APPENDIX B
Post-test questionnaires

Name:...

Class:.................................. Date:...

PART A

Study carefully the simulation. Afterwards, answer the following questions.

1. Describe carefully and in detail what you see happening in the simulation-no explanation needed!
....
....
....
....
....
....

2. (a) For each of the events in the simulation described above: explain as best as you can why they occurred.
....
....
....
....
....
....

(b) At the very BEGINNING of the simulation event, is there any energy?

YES or NO?
Choose one. [ ]

If YES, where?
....
....

If NO, why not?
....
....
....

3. Think now about the END of the simulation event, when the ball has stopped moving.

Is there any energy?
YES or NO?
Choose one. ☐

If YES, explain.

....

....

....

If NO, why not?

....

....

....

4. What can you say about the amount of energy at the BEGINNING compared with the amount of energy at the END?

....

....

....

5. Finally, describe overall what has happened to the energy of the event from BEGINNING to END.

....

....

....

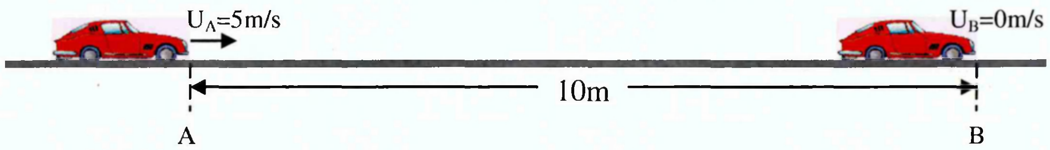
....

....

....

PART B

1. A car is traveling along the road with a constant speed of 5m/s.



At point A, it runs out of petrol and its engine stops working. The car moves for another 10m before finally stopping at point B.

(a) Was any energy stored in the system at point B?

Answer YES/NO

If YES, name that energy and calculate how much there is.

....

....

If NO explain why there is no energy.

....

....

b. What has happened to that **amount** of energy at point B? Compare it to that at point A. In what they are similar and in what they differ? Justify your answer.

....

....

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....

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c. Describe in words or in any other way and in much detail as you can, what has happened to the energy of the system from point A to point B.

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d. Calculate the force (F) between the wheels of the car and the road in order the car to stop at point B.

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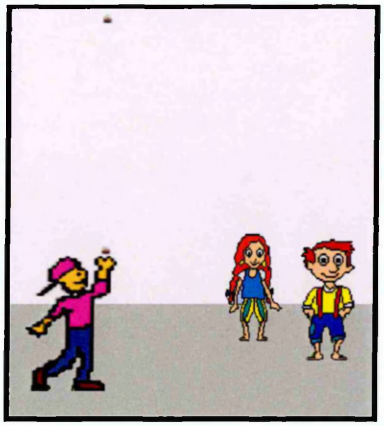
2. George makes a bet with his friends Helena and John that he can throw a coin up to a height of 5m.



(a) As the coin moves up through the air it has kinetic energy. Where does it get this energy from?

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(b) At the top of its flight the coin is stationary for a moment. Where is the energy now?

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(c) Calculate the energy of the coin when it reaches the height of 5m (the mass of the coin is 0.003Kg and $g=10m/s^2$).

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(d) Taking account of the energy at the 5m height, which you have just calculated: calculate the initial speed of the coin as it leaves George's hand.

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(e) George throws the coin upwards giving it the initial speed needed to reach the height of 5m and John measures the height. Surprisingly, they see that the coin reached only a height of 4.90m and not at 5m. George repeats the throw of the coin and John measures the height it reaches and its again 4.90m.

Explain why that happens in terms of energy. Use words or any other way in your explanation.

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APPENDIX C

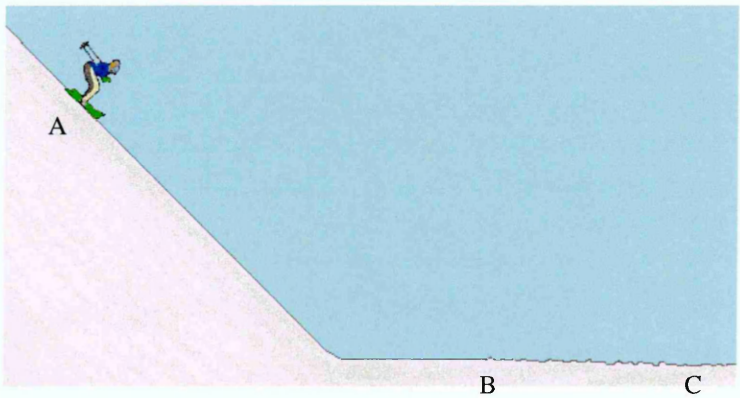
First short-length diagnostic probe

Name:...

Class:.................................. **Date:**..

Study carefully the image below. Afterwards, answer the following questions.

A skier starts to slide on a smooth snowed mountain slope from point A down to a snowed horizontal plane which is smooth up to point B. The skier stops at point C after he covers distance BC where the snow is rough.



(I) a. Make an energy description of the process which takes place in the system. In your description, be referred to distances AB and BC respectively.
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b. Draw the Full Sequence Energy Diagram of the system. In your drawing, consider as sub events the sliding of the skier for the distances AB and BC respectively.

c. A young skier, Mary, watches the skier's sliding from point A down to point C and thinks that, the energy of the system at the start is greater than energy at the end. Do you agree or disagree? Explain your answer.

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(II) a. Describe what would happen if the horizontal plane at distance BC was smooth.

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ii. Interpret in terms of energy and in detail the description you made above.

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APPENDIX D

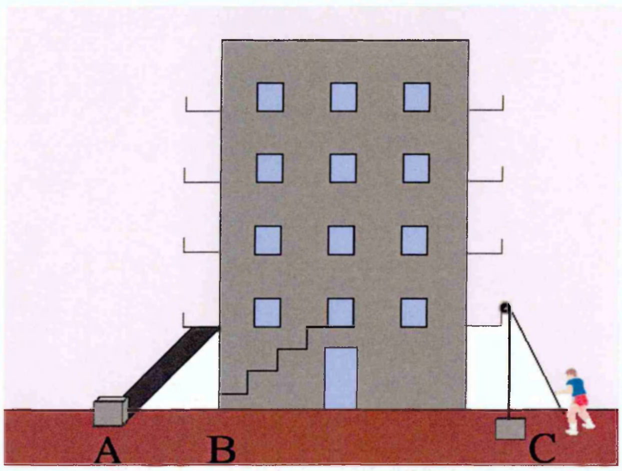
Second short-length diagnostic probe

Name:..

Class:.................................... **Date:**..

Study carefully the image below. Afterwards, answer the following questions.

(I) In the image below, a worker lifts a box up to the first floor of a building. In order to do so, he can choose one of three ways: (a) pushing it on a smooth inclined plane (way A), using the stairs (way B) or, using a frictionless pulley (way C).



(1) A student, Andrew, watches the worker in attempting to lift up the box and he thinks that, mechanical working done by the force exerted by the worker on the box is greater when the worker uses the stairs (way B). Do you agree or disagree? Explain your answer.

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(2) Andrew also thinks that, the amount of energy stored in the system box-Earth after the box is lifted on the first floor by the worker using the stairs (way B) is greater. Do you agree or disagree? Explain your answer.

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(II) The worker finally decides to lift the box up to the first floor by pushing it on the smooth inclined plane (way A).

1. Make the energy description of the process which takes place in the system.

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2. Draw the Sankey diagram of the system.

(3) Having watched all the lifting up process, Andrew thinks that the energy of the system is greater at the start than at the end. Do you agree or disagree? Explain your answer.

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APPENDIX E
First interview protocol

Two classmates, Michael and Niki, leave a crystalline marble to roll on the metallic rail illustrated in the image.

Michael claims that the marble will roll from point A down to point B, hence from point B to point C and then, from point C up to point E.

However, Niki disagrees with Michael and claims that, the marble will roll from point A down to point B, hence from point B to point C and then, from point C up to point D.

1. With which of the two students do you agree?

2. Why do you agree with Michael/Niki?

3. Look at these two diagrams.

a. What the rectangles represent?

b. What the arrows represent?

c. What are the energy stores?

d. Do the energy stores exist?

e. What are the transfer pathways of energy?

f. Do the transfer pathways exist?

g. What is the purpose of using the ideas of the energy stores and transfer pathways in physics?

h. Which diagram do you think describes best the process of the system of the image?

i. Why do you think is this?

j. Can you complete the names of the energy stores and the transfer pathways on the diagram?

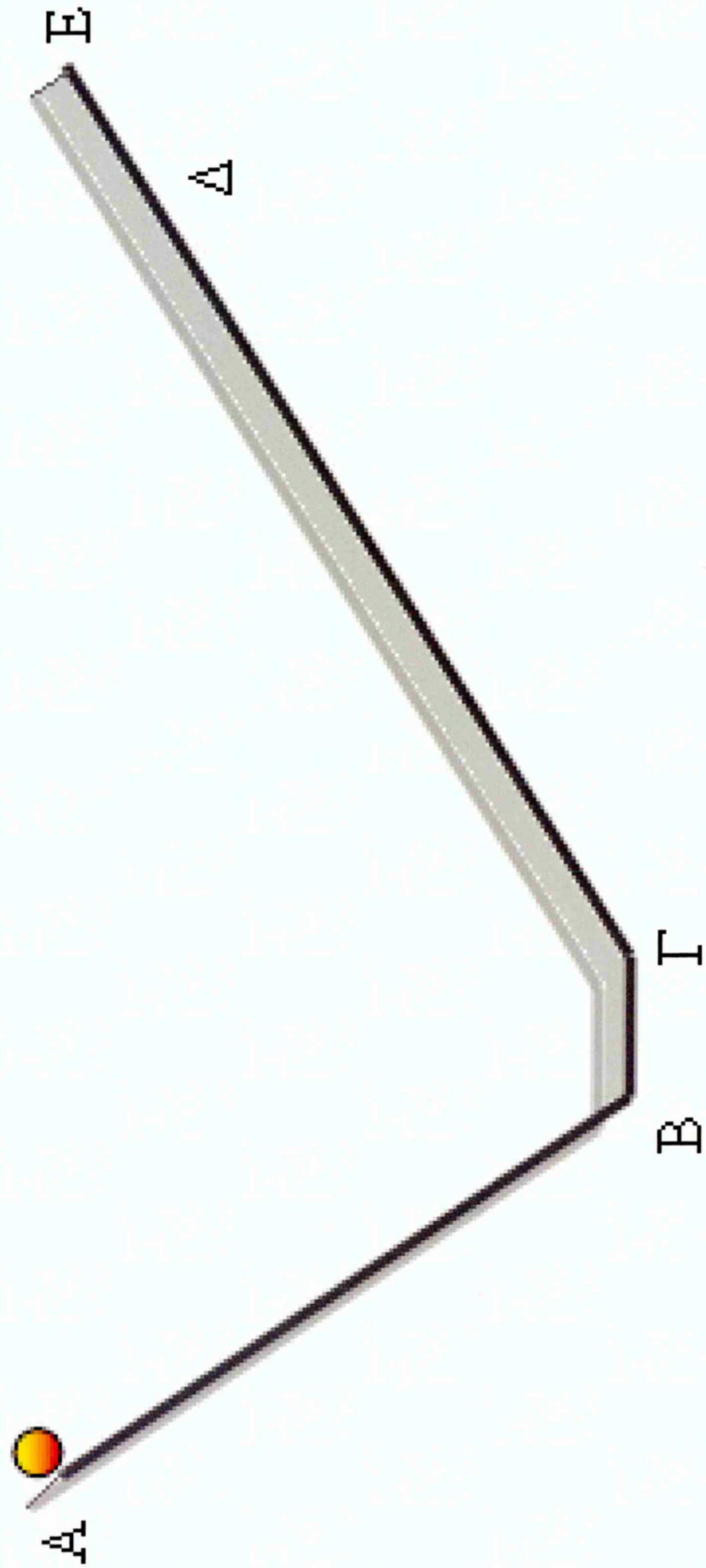
k. What can you tell me about the amount of energy at the beginning and the end of the process?

4. If the marble is let to continue its movement, describe how this will be.

5. Why the marble will do this kind of movement?

6. Is there energy at the end?

7. Where energy goes at the end?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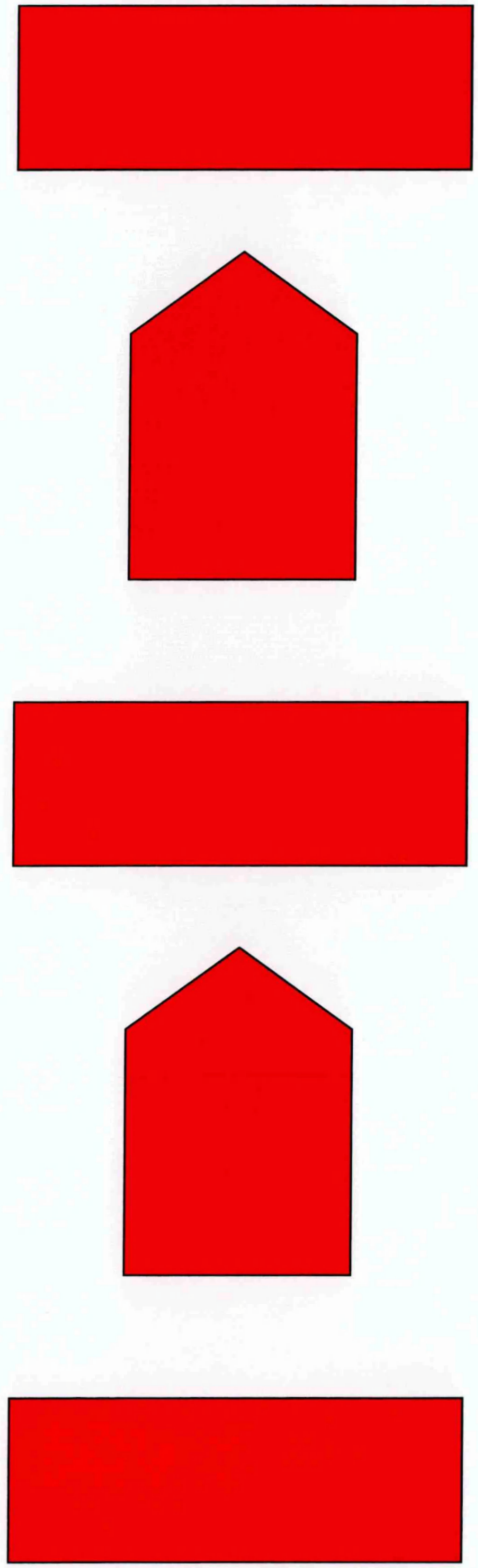
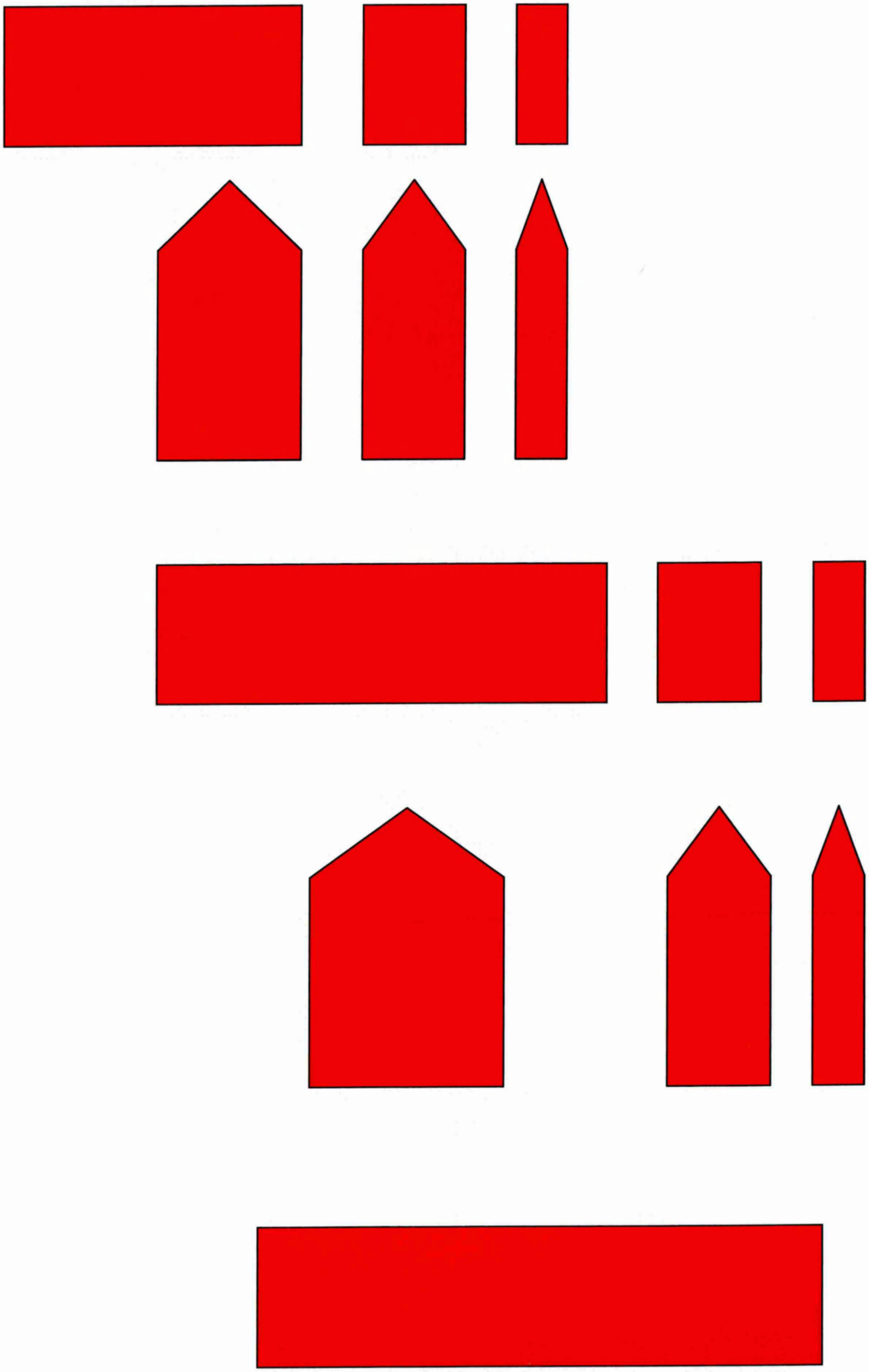




APPENDIX F
Second interview protocol

The man of the image plays golf on a horizontal field. He hits the ball with his stick and the ball rolls towards the flag and stops beside it.

1. How do you interpret this physical process?

2. Look at these two diagrams.

a. Which of these do you think that describes best the process of the system of the image?

b. Why do you think is this?

c. Can you make a full energy description of the process?

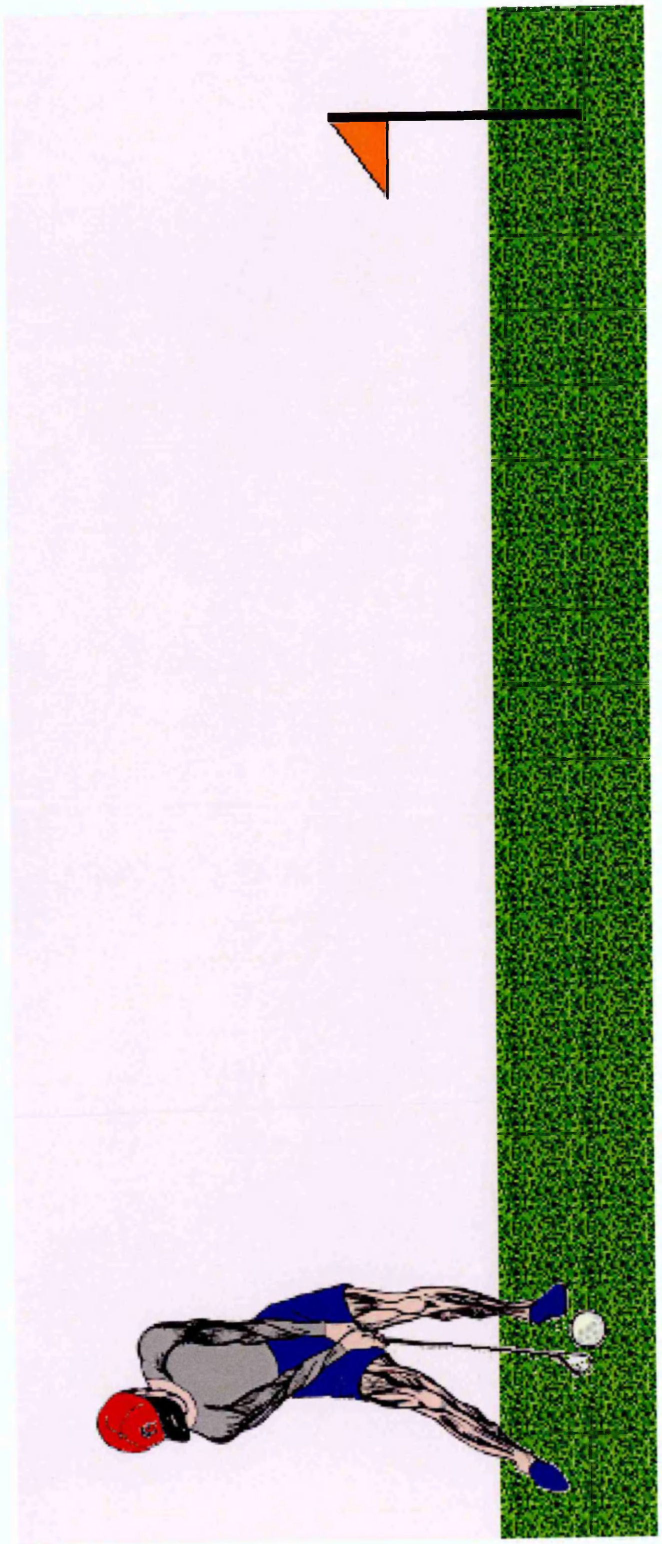
d. Can you complete the diagram?

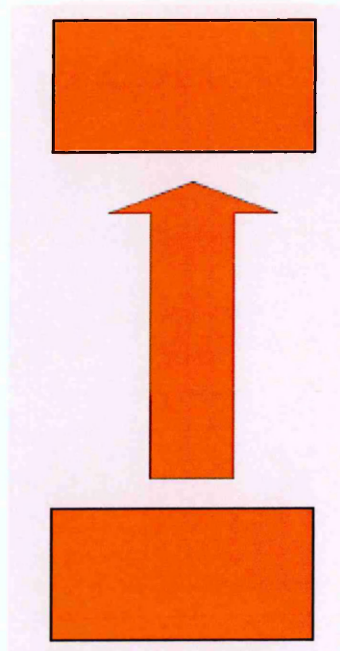
e. What can you tell me about the amount of energy at the beginning and the end of the process?

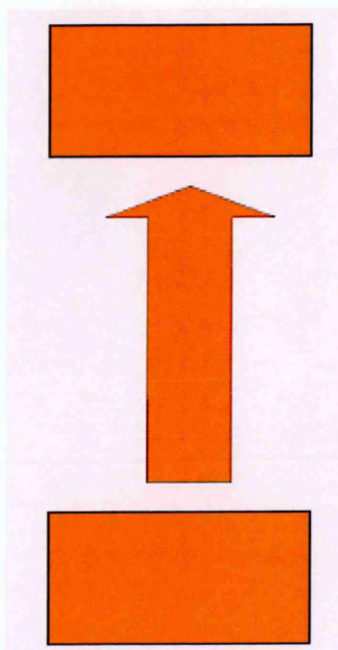
f. Where the energy goes at the end of the process?

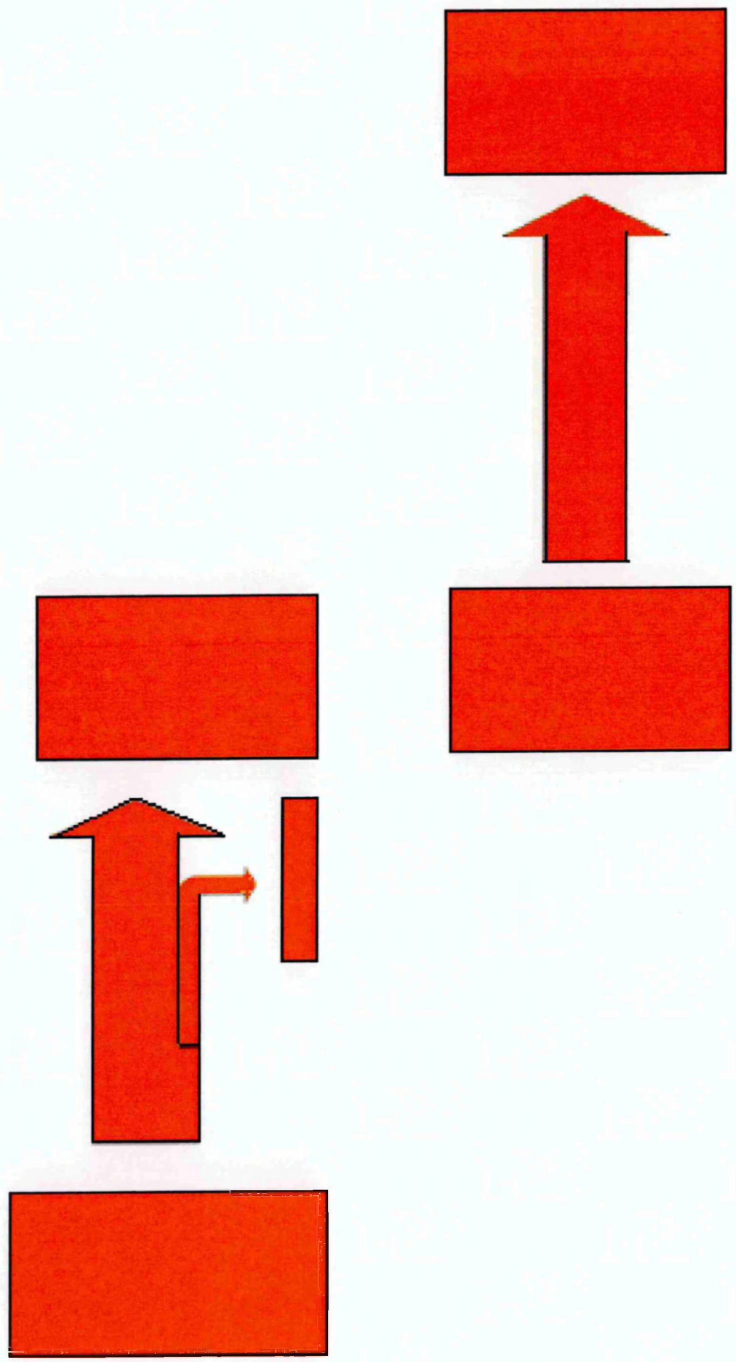
3. Energy exists?

4. What is the purpose of using the idea of energy in physics?





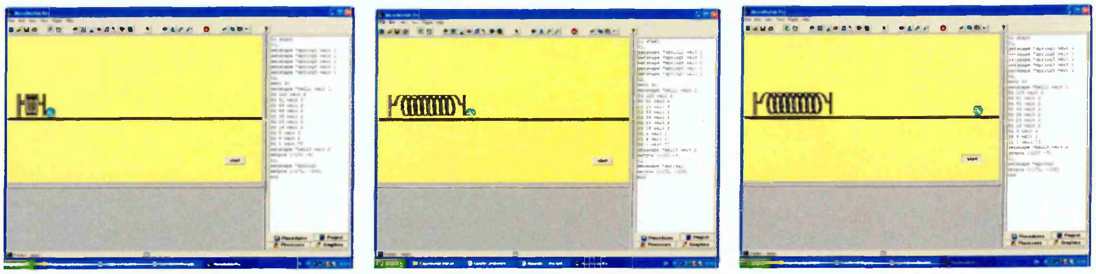




APPENDIX G

Model correct responses for pre-test questions

Study carefully the simulation. Afterwards, answer the following questions.



1. Describe carefully and in detail what you see happening in the simulation-no explanation needed!

Full response: *The compressed spring expands and sets the ball into motion. The ball decelerates and finally comes to rest.*

Partially full response: *The compressed spring expands and sets the ball into a decelerated motion/into motion.*

Incomplete response: *The compressed spring expands and hits the ball.*

2. (a) For each of the events in the simulation described above: explain as best as you can why they occurred.

Energy-based interpretation: *Events occurred because of energy.*

(b) At the very BEGINNING of the simulation event, is there any energy?

YES or NO? Choose one.	*YES*

If YES, where?

There is energy in the compressed spring.

If NO, why not?

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....

3. Think now about the END of the simulation event, when the ball has stopped moving.

Is there any energy? YES or NO? Choose one.	*YES*

If YES, explain.

There is energy at the end because energy can be transferred from one place to another/because energy remains the same.

If NO, why not?

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....

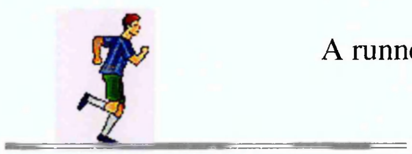
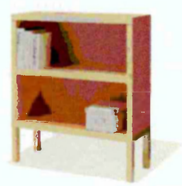
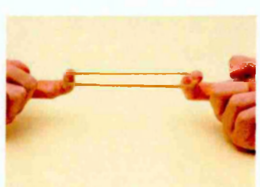
4. What can you say about the amount of energy at the BEGINNING compared with the amount of energy at the END?

The amount of energy at the beginning is the same with the amount of energy at the end.

5. Finally, describe overall what has happened to the energy of the event from BEGINNING to END.

The energy of the compressed spring is transferred to the moving ball and then, once the ball comes to rest, to the environment/ to the environment as heat.

6. Look at the following. Which of them has energy? Give a brief explanation.

OBJECT	YES/NO	EXPLANATION
1.  A moving car	*YES*	*There is energy of the moving car /There is kinetic energy.*
2.  A battery	*No*	*There isn't any energy because no chemical reaction takes place.*
3.  A runner	*YES*	*There is energy of the moving athlete /There is kinetic energy.*
4.  A book on a shelf	*YES*	*There is energy because the book is at a raised position from the floor/There is gravitational energy.*
5.  A barrel of petrol	*No*	*There isn't any energy because no chemical reaction takes place.*
6.  A stretched elastic band.	*YES*	*There is energy because the elastic band is stretched/disfigured/There is elastic energy.*

APPENDIX H

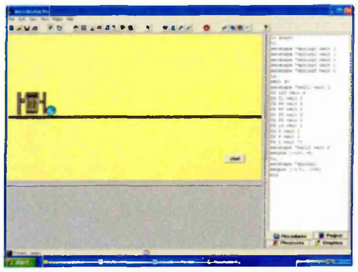
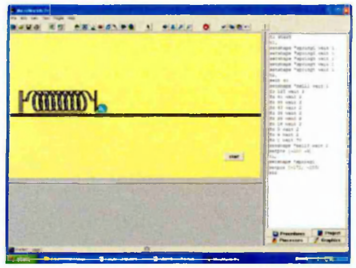
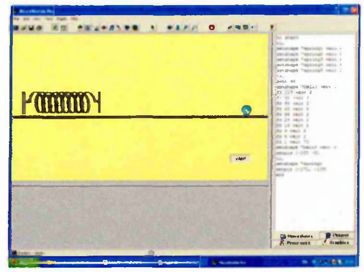
Coding scheme of energy models

Correct energy model See model correct responses in Appendix G.
Anthropocentric model Energy is associated with living organisms and specifically with human beings and also with objects which are considered to possess human characteristics.
Depository model Specific substances, objects or media such as fuels, food and batteries can store energy, need energy or consume energy which is stored in them. Energy is considered as the causal agent which is stored in specific objects.
Ingredient model Energy is associated with fluids or ingredients that are dormant and are released suddenly by a trigger.
Activity model Energy is associated with motion, force and activity.
Product model Energy is viewed as a kind of by-product of a situation that is generated, is active, and then disappears or fades.
Functional model Energy is percept as a fuel the amounts of which are limited.
Flow-transfer model Energy is considered as a fluid which can flow from one object to another.
No implicit model Yes, there is energy/No, there isn't energy.

APPENDIX I

Model correct responses for post-test questions according to 'new approach'

Study carefully the simulation. Afterwards, answer the following questions.

1. Describe carefully and in detail what you see happening in the simulation-no explanation needed!

Full response: *The compressed spring expands and sets the ball into motion. The ball decelerates and finally comes to rest.*

Partially full response: *The compressed spring expands and sets the ball into a decelerated motion/into motion.*

Incomplete response: *The compressed spring expands and hits the ball.*

2. (a) For each of the events in the simulation described above: explain as best as you can why they occurred.

Energy-based interpretation: *Events happen because there is energy in the system. The energy of the system is initially in the elastic store of the compressed spring, hence it is transferred to the kinetic store of the moving ball and the internal store of the surrounding air and then, once the ball stops moving, to the internal store of the ball, the surrounding air and the ground.*

(b) At the very BEGINNING of the simulation event, is there any energy?

YES or NO?
Choose one.

YES

If YES, where?

There is energy in the elastic store of the compressed spring.

If NO, why not?

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....
....

3. Think now about the END of the simulation event, when the ball has stopped moving.

Is there any energy?
YES or NO?
Choose one.

YES

If YES, explain.

There is energy at the end because it can be transferred from one place to another/because energy remains the same.

If NO, why not?

....
....
....

4. What can you say about the amount of energy at the BEGINNING compared with the amount of energy at the END?

The amount of energy at the beginning is the same with the amount of energy at the end.

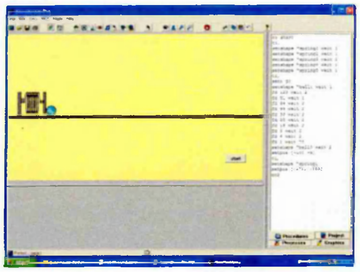
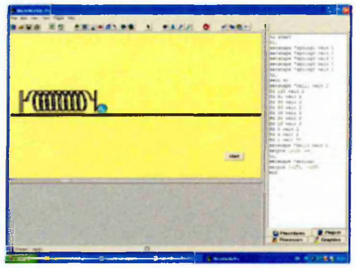
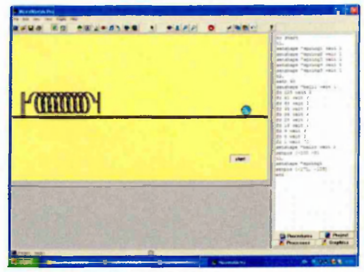
5. Finally, describe overall what has happened to the energy of the event from BEGINNING to END.

Energy description: *The energy of the system is initially in the elastic store of the compressed spring, hence it is transferred along a mechanical working pathway to the kinetic store of the moving ball and along a sound pathway to the internal store of the surrounding air and then, along a heating pathway to the internal store of the ball, the surrounding air and the ground along a sound pathway to the internal store of the surrounding air.*

APPENDIX J

Model correct responses for post-test questions according to 'normal approach'

Study carefully the simulation. Afterwards, answer the following questions.

1. Describe carefully and in detail what you see happening in the simulation-no explanation needed!

Full response: *The compressed spring expands and sets the ball into motion. The ball decelerates and finally comes to rest.*

Partially full response: *The compressed spring expands and sets the ball into a decelerated motion/into motion.*

Incomplete response: *The compressed spring expands and hits the ball.*

2. (a) For each of the events in the simulation described above: explain as best as you can why they occurred.

Energy-based interpretation: *Events happen because of energy. The energy is initially in the form of elastic potential in the compressed spring, hence it is converted in the form of kinetic to the moving ball and then is transferred as heat to the surrounding air, the ground and the ball.*

(b) At the very BEGINNING of the simulation event, is there any energy?

YES or NO?
Choose one. | *YES*

If YES, where?

There is elastic energy in the compressed spring.

If NO, why not?

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3. Think now about the END of the simulation event, when the ball has stopped moving.

Is there any energy?
YES or NO?
Choose one.

YES

If YES, explain.

There is energy at the end because it can be transferred from one place to another/because energy remains the same.

If NO, why not?

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4. What can you say about the amount of energy at the BEGINNING compared with the amount of energy at the END?

The amount of energy at the beginning is the same with the amount of energy at the end.

5. Finally, describe overall what has happened to the energy of the event from BEGINNING to END.

Energy description: *The energy is initially in the form of elastic potential in the compressed spring, hence it is converted to mechanical work and transferred to the ball where it is converted to kinetic and then it is transferred as heat to the surrounding air, the ground and the ball.*

Appendix K

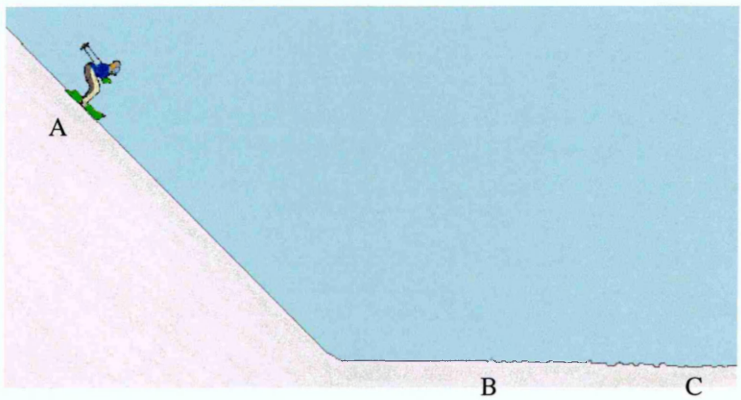
Model correct responses for first short-length diagnostic probe

Name:..

Class:.................................... **Date:**..

Study carefully the image below. Afterwards, answer the following questions.

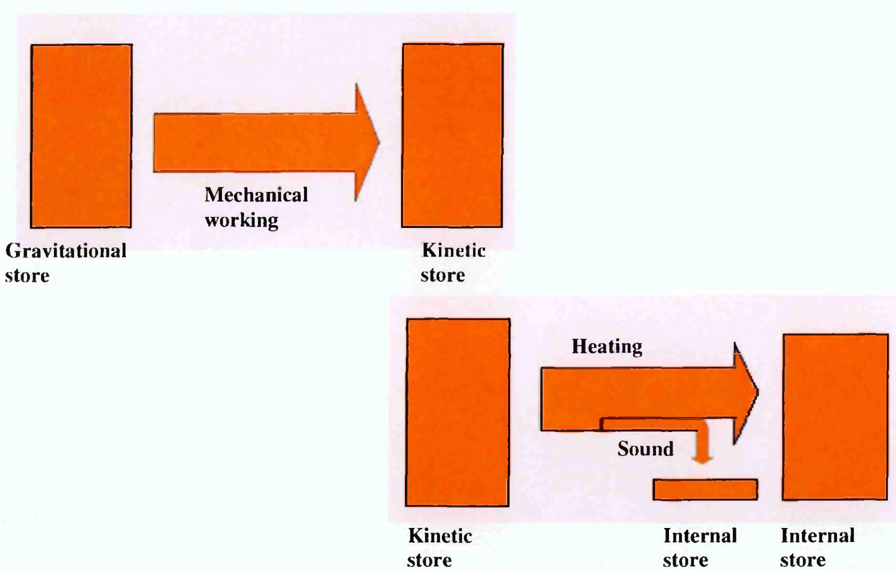
A skier starts to slide on a smooth snowed mountain slope from point A down to a snowed horizontal plane which is smooth up to point B. The skier stops at point C after he covers distance BC where the snow is rough.



(I) a. Make an energy description of the process which takes place in the system. In your description, be referred to distances AB and BC respectively.

The energy in the gravitational store of the system skier-earth at point A is transferred along a mechanical working pathway to the kinetic store of the skier at point B. Then, the energy in the kinetic store is transferred along a heating pathway to the internal store of the snowed horizontal plane, the skies and the surrounding air and along a sound pathway to the internal store of the surrounding air at point C.

b. Draw the Full Sequence Energy Diagram of the system. In your drawing, consider as sub events the sliding of the skier for the distances AB and BC respectively.



c. A young skier, Mary, watches the skier's sliding from point A down to point C and thinks that, the energy of the system at the start is greater than energy at the end. Do you agree or disagree? Explain your answer.

I disagree. The energy of the system is conserved and thus the amount of energy in the gravitational store at point A equals that in the kinetic store at point B.

(II) a. Describe what would happen if the horizontal plane at distance BC was smooth.

The skier would not stop at point C. He would move with constant speed that he had at point B.

ii. Interpret in terms of energy and in detail the description you made above.

The amount of energy in the kinetic store of the skier at point B remains the same since there would be no transfers of energy along a heating pathway to an internal store.

APPENDIX L

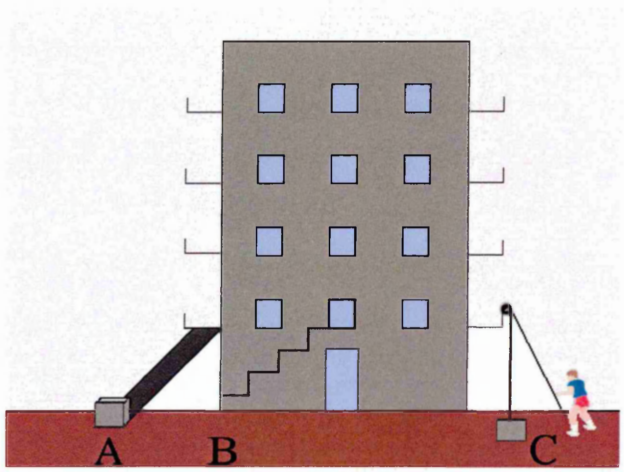
Model correct responses for second short-length diagnostic probe

Name:...

Class:...................................   Date:...

Study carefully the image below. Afterwards, answer the following questions.

(I) In the image below, a worker lifts a box up to the first floor of a building. In order to do so, he can choose one of three ways: (a) pushing it on a smooth inclined plane (way A), using the stairs (way B) or, using a frictionless pulley (way C).



(1) A student, Andrew, watches the worker in attempting to lift up the box and he thinks that, mechanical working done by the force exerted by the worker on the box is greater when the worker uses the stairs (way B). Do you agree or disagree? Explain your answer.

I disagree. Mechanical working done by the force exerted by the worker does not depend on the pathway followed but only on the vertical distance between the initial and the final position of the box.

(2) Andrew also thinks that, the amount of energy stored in the system box-Earth after the box is lifted on the first floor by the worker using the stairs (way B) is greater. Do you agree or disagree? Explain your answer.

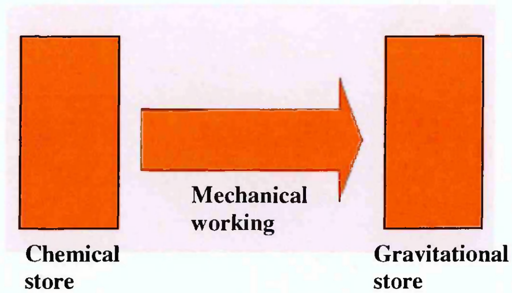
I disagree. The amount of energy in the gravitational store of the system box-earth is the same for all three ways since this is directly proportional to the height at which the box is lifted up and not depended on the path followed from the initial to the final position.

(II) The worker finally decides to lift the box up to the first floor by pushing it on the smooth inclined plane (way A).

1. Make the energy description of the process which takes place in the system.

The energy in the chemical store of the worker is transferred along a mechanical working pathway to the gravitational store of the system box-earth.

2. Draw the Sankey diagram of the system.



(3) Having watched all the lifting up process, Andrew thinks that the energy of the system is greater at the start than at the end. Do you agree or disagree? Explain your answer.

I disagree. The energy of the system is conserved and thus the amount of energy in the chemical store of the worker equals the amount of energy in the gravitational store of the system box-earth.

APPENDIX M

Model correct responses for the first interview questions

1. I agree with Niki.

2. Because the energy in the gravitational store at point A is not all transferred in a gravitational store at the end but also to an internal store; thus, the marble will not reach point E but point D.

3. a. They represent the energy stores.

   b. They represent the transfer pathways of energy.

   c. Energy stores are places in a system at which energy can be found.

   d. No.

   e. Transfer pathways are mechanisms or processes with which energy is transferred from one store to another.

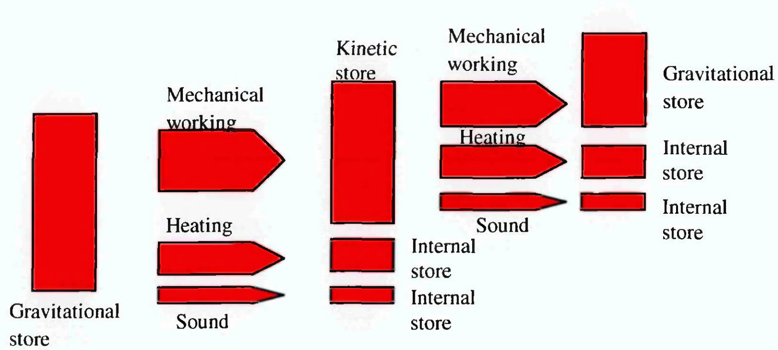
   f. No.

   g. They provide a way for interpreting the changes observed in a system as a physical process takes place in it.

   h. The second one.

   i. Energy is not transferred along only one transfer pathway but along a mechanical working, a heating and a sound pathway.

   j.



k. The amount of energy at the beginning equals the amount of energy at the end because the energy of the system is conserved.

4. The marble will reach less and less height and finally will stop between points B and C.

5. Because the energy of the system is degraded, that is, it is transferred from the gravitational and the kinetic store to the internal store.

6. Energy is finally stored in the internal store of the metallic rail, the marble and the surrounding air.

APPENDIX N
Model correct responses for the second interview questions

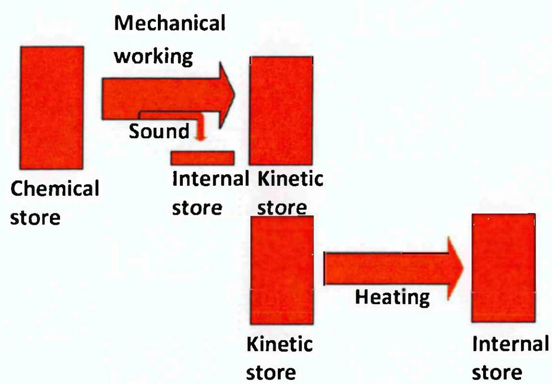
1. There is energy in the system which is transferred from one place of it to another.

2. a. The second one.

b. The energy in the chemical store of the man is transferred along two transfer pathways, along a mechanical working and a sound pathway.

c. The energy in the chemical store of the man is transferred along a mechanical working pathway to the kinetic store of the ball and along a sound pathway to the internal store of the surrounding air. Then, the energy in the kinetic store is transferred along a heating pathway to the internal store of the ground, the ball and the surrounding air.

d.



e. The amount of energy at the beginning equals the amount of energy at the end because the energy of the system is conserved.

f. It is degraded, that is, it is stored in an internal store.

3. No, it is a human's invention.

4. The idea of energy is used for the interpretation of the observed changes in a system as a physical process takes place in it.

APPENDIX O

Design briefs: a detailed design specification for establishing and communicating knowledge about instruction of a specific content

An issue of crucial importance in science education research concerns the ways in which knowledge claims about the instruction of a specific scientific content could be established and communicated for maximizing students' understanding. Working in this direction, Leach, Ametller and Scott (2011) propose the development of 'design briefs' which they define as follows: 'The purpose of design briefs is to make explicit the design intentions for a piece of science teaching, explaining why particular design decisions have been taken' (Leach et al., 2011, p. 10). Furthermore, the researchers identify the aspects which design briefs should include as follows: 'Design briefs address three aspects of a design specification of the teaching:

- the context for the designed teaching;
- the detailed content aims of the teaching;
- specification of the pedagogic strategies and sequencing of content to be used in the teaching' (Leach et al., 2011, p. 10).

The first aspect of the design briefs should provide information concerning three key issues: for the curriculum of the specific scientific context. This aims to enable communication of design decisions between designers addressing different syllabi in different national systems but retaining insights from learning theory and empirical evidence about students' likely ways of explaining phenomena prior to instruction; the participating students and teachers and; any institutional constrains might exist. According to the researchers, this information could be provided through answers to a set of suitable questions to four key issues as follows:

- *'Curriculum*: What is the topic area, and how does it feature in the relevant curriculum? (What are the core ideas to be taught, what has been studied previously, what is to be studied later on the curriculum?)
- *Students*: How old are the students, what is the ability profile of the class? Are there any features of students' expectations of science lessons that need to be taken into account in the design of the teaching?
- *Teachers:* Are the teachers specialist science teachers or not, and if so what is their disciplinary background? Are there any features of the teachers' expertise

or expectations of science lessons that need to be taken into account in the design of teaching?

- *Institutional constrains:* What is the class size? What teaching facilities are available? What time is available for the topic? What requirements are imposed by local regimes (e.g. assessment, homework)?' (Leach et al., 2011, p. 11).

As the researchers stress, this section of design briefs should enable the readers, researchers and others, to make their own judgments about the applicability of the proposed instructional sequence in different contexts; 'good science teaching' considerations often differ in different national contexts.

The second aspect of design briefs, involves the specification and justification of the content aims of the teaching. As the researchers propose, such decision could be informed by an analysis using the 'learning demands' design tool (Leach and Scott, 2002, p. 125) followed by the specification of the 'teaching goals' (Scott, Leach, Hind and Lewis, 2006, p. 65) which could address the learning demands. The concepts of 'learning demands' and 'teaching goals' are presented and discussed in detail in section 4.5.

Finally, the third aspect of design briefs involves the specification and justification of the pedagogic strategies and sequencing of content to be used in teaching. Drawing upon a constructivistic perspective on learning (Leach and Scott, 2003), the researchers propose the 'communicative approach' design tool (Scott et al., 2006) to link the teacher/whole class talk with teaching intentions. Communicative approach is presented and discussed in detail in section 4.8. Furthermore, they propose 'three fundamental issues that have to be addressed in the design of science teaching addressing specific content to maximize understanding. These are:

- *Staging the scientific story:* How is the target scientific model to be introduced to students?
- *Supporting student internalization:* How will opportunities be provided for students to begin to try out new ideas with other students or the teacher, and how will the teacher check students developing understanding? The term 'internalization' was proposed by Vygotsky (1978) to define the process of

students' personal sense-making of the scientific point of view introduced to the class (the social plane) by the teacher.

- *Handing-over responsibility to students:* How will students become able to use newly-introduced content for themselves, with some opportunity for re-expression?' (Leach et al., 2011, p. 13).

The first key feature of the instructional process relates to the way the scientific point of view is made available to students. Leach and Scott (2002) propose that the scientific point of view could be gradually developed through a teacher-led process which might involve a variety of teaching activities during the sequence of lessons.

The second key feature relates to the ways the teacher might act to help students make sense of, and apply the scientific point of view presented during the first stage of the instructional process. According to Leach and Scott (2002, p. 123), one way in which the teacher could support students' internalisation is through '... the continuous monitoring of students' understandings and responding to those understandings, in terms of how they relate to the intended scientific point of view ...'.

Finally, the third feature of the instructional process relates to involving students into activities aiming to support the step of internalisation. Leach and Scott (2002, p. 124) propose that this step '... involves providing opportunities for students to 'try out' and practice the new ideas for themselves, to make the new ideas 'their own''. Furthermore, they propose that as the students become more competent and confident in dealing with the scientific point of view, the teacher should gradually restrict his/her support and hand-over the learning responsibility to them.

APPENDIX P

Energy in the Cyprus Educational System

In the Cyprus Educational System, the formal instruction of energy begins in the sixth grade (students aged 11-12 years) of primary school. This takes place in the third trimester within the time of six 40-minute lessons with the focus being placed on the presentation of forms of energy, energy sources and the description of energy transformations from one form to another.

The content of the curriculum concerning energy for the sixth grade of primary school is illustrated in detail in Table1.

Table1: Cyprus National Curriculum for Physics for the sixth grade of Primary School.

CONTENT	TEACHING GOALS	LESSONS
CHAPTER 9 **Energy**	The child:	6
Forms of energy	1. be introduced to the energy concept through reference to a) domestic devices which need energy for their function b) various kinds of food which can give energy 2. distinguish and name forms of energy (heat, light, kinetic, sound, electric, chemical, elastic).	2
Transformation of energy	1. understand that a form of energy can be transformed into another form 2. be able to distinguish between the initial and the final form of energy when an energy transformation takes place in an everyday device 3. be able to relate with the use of given images the energy calories a) spent in a day of typical activities b) taken with food in a day.	2
Energy sources	1. know that electric energy in power stations is produced by a turbine, motor and a generator 2. know that electric energy can be produced using a) the power of moving water b) the power of steam 3. name least six energy sources 4. categorize energy sources into	2

	a) renewable and non-renewable b) those which can produce electric energy with the power of moving water and to those with the power of steam c) sources which cause environmental pollution and 'clean' sources.	

Energy appears again in the second grade of lower secondary school (students aged 13-14 years). As it is defined in the curriculum, its instruction takes place in the first trimester within the time of seven lessons first in the chapter of Matter and Energy and then as a brief part of Heat. The focus is placed on the presentation of forms of energy and sources of energy whereas energy transformations from one form to another and the conservation of energy principle are briefly presented. Furthermore, the detailed content of the curriculum for the second grade of lower secondary school concerning energy is illustrated in Table 2.

Table 2: Cyprus National Curriculum for Physics for the second grade of lower secondary school.

CONTENT	TEACHING GOALS	LESSONS
CHAPTER 2 Matter and Energy	The students should:	7
... **2.6. Forms and sources of energy.**	... 2.6.1 Become familiar with the concept of energy through examples. 2.6. 2 Relate the food taken by the organisms to the need of using energy for the activities of organisms. 2.6.3 Recognize that energy and matter interact. 2.6.4 Distinguish between the different forms of energy (chemical, electrical, nuclear, gravitational, potential, kinetic, solar and heat). 2.6.5 Refer the units of energy: calorie and joule and the relation between them. 2.6.6 Estimate characteristic values of energy amounts in examples of everyday life.	2
2.7 Renewable and non-renewable sources of energy	2.7.1 Distinguish between renewable and non-renewable sources of energy. 6.4.3 Define the power unit in S.I. 2.7.2 Know the factors which affect negatively or positively the human's quality of life in relation to the use of non-renewable sources of energy.	2

2.8 Transformation of energy **2.9 Conservation of energy**	2.8.1 Recognize in experimental process the transformation of energy from one form into another. 2.9.1 Calculate the work done by the weight in the case where the magnitude of weight is approximately constant.	0.5 0.5
CHAPTER 3 Heat	The students should:	19
… **3.2 Heat** **3.3 Thermal equilibrium** …	3.2.1 Formulate the definition of heat. 3.3.1 Define and prove experimentally thermal equilibrium.	1

The instruction of energy continues in the first grade of upper secondary school in an individual chapter and takes place in the third trimester within the time of eight lessons. The conceptual sequence followed leads to a more traditional approach for the instruction of energy with its origin in classical mechanics. The starting point of this sequence is the introduction of the concept of work, then it proceeds to the introduction of kinetic energy and potential energy (elastic and gravitational), to treatment of the transformations between these mechanical forms and finally, to the introduction of the energy conservation principle of mechanics. Furthermore, much emphasis is placed on the quantitative application of the conservation principle of mechanics in the analysis of energy problems. The content of the curriculum for the first grade of upper secondary school concerning energy is illustrated in Table 3.

Table 3: Cyprus National Curriculum for Physics for the first grade of upper secondary school.

CONTENT	TEACHING GOALS	LESSONS
CHAPTER 6 Work, Power and Energy	The students should:	8
6.1. Work done by a constant force.	6.1.1 Recognize that when a force is exerted on an object initially at rest and causes its movement, there is an amount of energy transfer to the object, called work done by the force. 6.1.2 Interpret the positive, negative or zero value of the work done by a force (in each case). 6.1.3 Calculate the work done by the constant force.	1

6.2. Work done by a variable force whose direction is constant.	6.2.1 Calculate the work done by a variable force whose direction is constant.	1
6.3. Kinetic energy and work-energy theorem.	6.3.1 Express the change in kinetic energy of an object as the work done by a resultant force which is exerted on it.	1
6.4. Power	6.4.1 Recognize how useful can be the calculation of the rate with which energy is transferred or transformed into another form (and to give examples). 6.4.2 Define power as the rate with which an amount of energy is transferred or transformed from one form into another. 6.4.3 Define the power unit in S.I.	1
6.5. Gravitational potential energy.	6.5.1 Recognize that within the gravitational field, work is done by the gravitational force (weight) which is exerted on the objects. 6.5.2 Define gravitational potential energy as the amount of energy stored in the system object-earth and relate gravitational potential energy to the work done by the weight. 6.5.3 Calculate the work done by the weight in the case where the magnitude of weight is approximately constant.	1
6.6. Elastic potential energy.	6.6.1 Verify experimentally Hooke's law. 6.6.2 Define elastic potential energy.	1 1
6.7. Mechanical energy and conservation of mechanical energy.	6.7.1 Define mechanical energy as the sun of the kinetic and the gravitational potential energy and explain the meaning of this sum.	1

Energy is also included in the advanced physics curriculum in the second grade (students aged 16-17 years) of upper secondary school where it is dealt with in a separate section in the context of mechanics. The instruction takes place in the first trimester within the time of six lessons. Regarding the content, this is a review of what is taught in the first grade with the emphasis being placed on more advanced quantitative applications in the analysis of energy problems in relation to motion. The content of the advanced physics curriculum for the second grade of upper secondary school concerning energy is illustrated in Table 4.

Table 4: Cyprus National Curriculum for Advanced Physics of the second grade of upper secondary school.		
CONTENT	**TEACHING GOALS**	**LESSONS**
CHAPTER 1 Mechanics in one dimension	The students should:	33
…	…	
1.2. Motion and Energy	1.2.1 Be able to calculate the kinetic energy of an object.	1
	1.2.2 Be able to refer examples in which kinetic energy remains the same.	
	1.2.3 Recognize and justify the fact that energy remains the same in the case of a linear uniform motion and changes in the case of a uniformly accelerated linear motion.	
	1.2.4 Define work done by a force as the scalar product of force and displacement and interpret the change in the kinetic energy of an object as the result of the action of a force in the direction of its velocity.	1
	1.2.5 Be able to formulate the work-kinetic energy theorem.	
	1.2.6 Be able to calculate the gravitational potential energy of an object near the earth's surface and recognize that energy is due to the interaction between the object and the Earth.	
	1.2.7 Be able to apply the conservation of mechanical energy theorem in problems of motion in one dimension.	3
…	1.2.8 Explain the energy transformations in the case of moving objects and describe qualitatively the change in their speed.	1
	…	