

Cross-Grade Comparison of Students' Understanding of Energy Concepts

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Abstract The aims of this cross-grade study were (1) to determine the level of understanding of energy concepts of students at different academic grades and the differences in understanding between these grades and (2) to analyse the conceptual development of these students. Two hundred and forty-three students at 3 different levels (high school, undergraduate, and postgraduate) participated in this study. The students' understandings of energy concepts were determined using a questionnaire, which requested them to define the concept verbally, and to represent it graphically. The most important findings of this study may be summarised as follows. Students from the different groups generally succeeded in defining 'energy' in a similar way, namely as the 'ability to do work'. Nevertheless, some students (including those at university) also provided different alternative conceptions related to the energy concept. In addition, some students also found difficulty in visually analysing the relationships between different variables using graphs. This finding could help explain why attainment levels of all groups falls short in questions that involve the graphical representation of data.

Keywords Cross-grade · Level of understanding · Conceptual development · Energy concepts

Introduction

Studies of alternative conception, in relation to conceptual understanding, are an important topic for education

researchers, and have been the subject of on-going research for many years. These studies have generally examined the alternative conceptions formed by students, and the reasons for the formation of these conceptions. According to the literature, the first of these reasons is the variety of use of the same concept in different disciplines and/or in daily language (Haidar and Abraham 1991; Çalık and Ayas 2005; Rowlands et al. 2007). The framework of Anthropological theory developed by Chevallard (1989) may be an effective tool for systematically examining and understanding the effects of these different uses of any concept on student learning, and on the development of their alternative conceptions. Under this theory, the knowledge of an individual (coded X) regarding any subject (coded O) in an institution (coded I) is defined as X 's *personal relation to O in I* . The theory suggests that while forming his/her knowledge of a concept, an individual is subject to the effects of his/her institution(s) i.e. the school(s) (s)he attends (high school/university etc.), the subject (mathematics, chemistry, history etc.), his/her family and daily life, among other influences. An individual's learning and the development of his/her alternative conceptions thus varies depending on the institution (s)he belongs to. Therefore, the formation or development of personal knowledge (conception, alternative conception, misconception, etc.) regarding a concept may be represented as follows:

Any concept O may be the subject of more than one institution, symbolised as I and I' , and this may cause differences in the definition, the meaning, the representation, etc. of the concept as it is used in these institutions (Fig. 1). According to the Anthropological Theory, alternative conceptions developed by an individual X of a concept are closely related to these differences and discrepancies.

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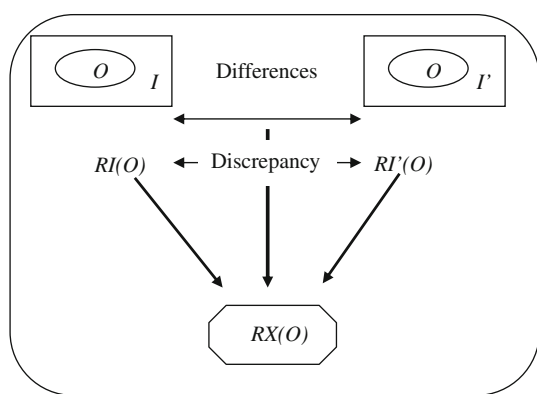


Fig. 1 Representation of the development of personal knowledge of a concept (Adapted from the figure given by Bui Thi 2005)

Theoretical Framework

The concept of energy is one of the most important ideas in physics, and one on which various alternative conceptions are developed, depending on its usage in various institutions such as in daily life, in physics and in biology (Kurnaz and Saglam Arslan 2009). It does not have a universal definition (Sefton 2004), and its complex character has intrigued a number of researchers for many years, and has generated many different research areas. These areas may be classified as follows: (a) *Description of energy* (e.g. Duit 1987; Kruger et al. 1992; Kaper and Goedhart 2002; Diakidoy et al. 2003), (b) *Teaching and/or learning energy* (e.g. Trumper and Gorsky 1993; Papadouris and Constantinou 2006; Kurnaz 2007; Papadouris et al. 2008), (c) *Students' conceptions related to the energy concepts* (e.g. Watts 1983; Duit 1984; Nicholls and Ogborn 1993; Goldring and Osborne 1994; Trumper 1998; Küçük et al. 2005; Köse et al. 2006) (d) *Alternative approaches to teach energy* (e.g. Trumper 1990, 1991; Huis and Berg 1993; Heuvelen and Zou 2001; Fry et al. 2003), (e) *Students' perception levels about energy and related concepts* (Watts 1983; Duit 1984; Goldring and Osborne 1994; Küçük et al. 2005; Ünal Çoban et al. 2007 and Hırça et al. 2008).

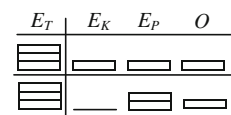
The researches mentioned above suggest that studies of students' conceptual development in relation to the concept of energy are somewhat limited. It is well known that cross-age study provides an opportunity to observe this development (Morgil and Yoruk 2006). Such studies allow the examination of changes both in the learning of concepts and in the development of alternative conceptions (Trowbridge and Mintzes 1988). Such studies also assist in the analysis of the effects of different institutions ($I, I' \dots$) on students' learning and on their development of alternative conceptions. The primary motive for exploring the often ignored effects of the institution (college, high school, university, etc.) is to provide meaningful information on

this topic that could yield appropriate and new methods for teachers and lecturers to teach students about energy.

In order to define the scope of this cross-grade study, we focused it on the concept of energy, which has abstract and theoretical characteristics (Diakidoy et al. 2003; Lemmer and Lemmer 2006). It was thus intended to carry out the study using alternative semiotic representations of the same concept.

Duval (1993) states that mathematical concepts may be only "concretised" by means of representations, because they do not exist in real life, and that treatments of these concepts are only possible using these representations. This fact may be generalised for all abstract concepts, which absolutely must be represented in at least one form (e.g. by oral expression, in a graph, table, or figure). Accordingly, the same concept may be represented in different semiotic systems (e.g. natural language representation [NL], symbolic representation [SR], graphical representation [GR], dynamic representation [DR]) (Séjourné and Tiberghien 2001). In physics, for example, frequency can be represented using a definition (NL), a formula (SR) or an animation (DR) (Séjourné and Tiberghien 2001). In the concept of energy, the total energy in a closed system can be represented in the following ways:

- Natural language representation: The total energy (E_T), consisting of kinetic (E_K), potential (E_P) and other forms of energy (O), remains constant in a closed system;
- Symbolic representation: $E_T = E_K + E_P + \text{other forms of energy}$;
- Visual representation by means of a diagram:



The proper use of different forms of representation is thus crucial (Duval 1995) if concepts are to be internalised and conceptualised by learners (Hiebert and Carpenter 1992; Duval 1995; Piez and Voxman 1997; Even 1998). Furthermore, according to Duval (1993), for any given concept there is a close relationship between an individual's level of conceptualisation and his/her ability to represent that concept using different forms of representation.

Purpose of the Research

In consideration of the role of the different forms of representation of a concept and that of the relationship between them on learners' conceptualisation, the aims of our study were to examine the conceptual developments of students at different levels and in different institutions in relation to the concept of energy, by analysing their ability

to describe this concept (NL representation) and to represent it graphically (GR). In contrast with previous studies, this paper discusses the effects of several institutions at different levels on students’ knowledge (using verbal and graphical representation).

The objectives of this research were:

- To investigate the achievement levels of students at different grades regarding:
 - The definition of the energy concept, and
 - Its graphical representation,
- To analyse the relationship between students’ achievement levels on the definition of the energy concept and on those of its graphical representation.

Methods

Sample

The study was completed in 2009 and used 243 participants at various levels of education, such as high school students, undergraduate students, and graduate students. By considering the characteristics of the sample, the students were classified into three groups. The first group, hereafter called Beginners (BE), consisted of 160 students in the 9th and 10th grades in four different high schools in the Eastern Black Sea Region of Turkey. These students had just

year of a university in the Eastern Black Sea Region and were accordingly about to complete their study of physics. The final group of Experts (EXP) consisted of 14 students who had completed their undergraduate education in a Physics Department in a Faculty of Arts and Science, and who then attended a Masters program at the same university, in order to gain a degree in education.

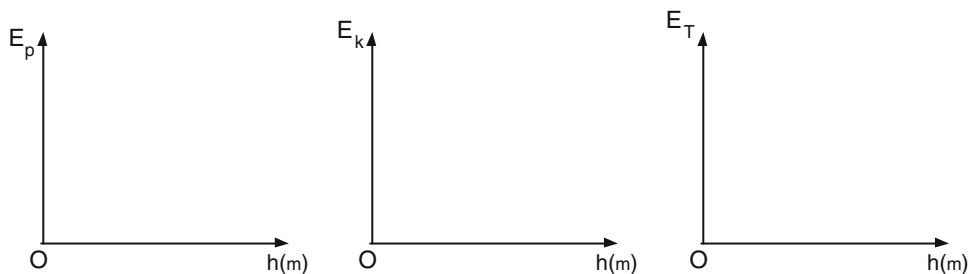
Instruments

In this study, we developed an achievement test, consisting of two sections, and used this as a data collection tool. The first section, related to the NL representation of the energy concept, consists of the question: *What is energy? Explain it.*

In the second section of the test, we investigated the GR of the concept and used two questions related to the same problem. In these questions, students were required to draw graphs using potential and kinetic energy formulas that were given to them, as follows:

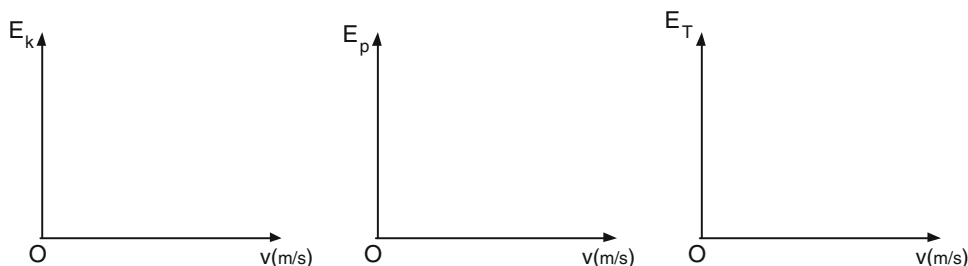
Problem: In a frictionless environment, an object with mass m is thrown vertically upwards with initial velocity V_0 . Please respond to the following questions by considering the upward motion of this object before it reaches the maximum point.

- (a) Draw the graphs of potential energy (E_p) versus height, kinetic energy (E_k) versus height, and total (E_T) energy versus height by referring to the equation $E_p = m \cdot g \cdot h$.



developed the energy concept in their physics courses. The Pre-experts (PE) group consisted of 69 teacher candidates who aspired to teach the beginner group in the future. They attended their physics teaching program in the 4th or 5th

- (b) Draw the graphs of kinetic energy (E_k) versus velocity, potential energy (E_p) versus velocity, and total (E_T) energy versus velocity by referring to the equation $E_k = \frac{1}{2} m \cdot V^2$.



The aim of the two questions above was to determine the ability of the students to draw graphs using an algebraic expression and by correlating the kinetic and potential energy graphs. The students were thus required to use the expression $E_P = m \cdot g \cdot h$ in part *a* (or $E_K = \frac{1}{2} m \cdot V^2$ in part *b*) in order to draw the graphical representation of the change in the potential (or kinetic for part *b*) energy of the object according to its height (or velocity for part *b*) for the first graphical representation in each case. Nevertheless, in order to draw the two other graphs in both questions, students had to interpret the graphical representation they had just drawn and then coordinate E_P and E_K .

Pilot Study

In order to test the data collection tool, the pilot study was conducted with the participation of 70 freshmen who were attending basic physics lessons, and the results obtained were not taken into account within the scope of this study. These students' papers showed that the questions introduced above were understandable and enabled the collection of data that was suited to the aim of this study.

Furthermore, in order to increase the validity and reliability of the instrument used in this study, the research questions and the achievement test were discussed with a group including two physics lecturers and two physics teachers. The instruments and research questions were finalised following this discussion.

Data Analysis

In consideration of the characteristics of the data collected during the study, two different methods of analysis were used:

In order to analyse students' verbal responses, a rubric developed by Abraham et al. (1994) to analyse students' levels of understanding was employed, which is frequently used in cross-age studies (e.g. Westbrook and Marek 1992; Pell and Jarvis 2001; Çalık and Ayas 2005; Saka et al. 2006). This system may be described as follows.

- [0] No Understanding (NU): Blank, repeats question; irrelevant or unclear response,
- [1] Alternative Conception (AC): Scientifically incorrect responses containing illogical or incorrect information,
- [2] Partial Understanding with Specific Alternative Conception (PU/AC): Responses showing that the concept is understood but also containing alternative conception,
- [3] Partial Understanding (PU): Responses containing some components of the scientifically accepted response,
- [4] Sound Understanding (SU): Responses containing all components of the scientifically accepted response.

The graphs drawn by students were analysed according to the rubric described below and developed by the researcher within the scope of this study, in parallel with the categories listed above.

- [0] No Drawing (ND): Blank.
- [1] Incorrect graph (IG): None of the graph drawn correctly.
- [2] Correct graph with incorrect graphs (CG/IGs): The graph directly related to the algebraic expression (i.e. the first graph in items *a* and *b*) is correct, but the other two graphs are incorrect.
- [3] Correct graphs with incorrect graph (CGs/IG): One of the graphs indirectly related to the algebraic expression is incorrect, but the other two graphs are correct.
- [4] Correct graphs (CG): All three graphs are correct.

Results

Each student's answers were firstly analysed according to the type of question (verbal or graphical), and the achievement level of the student was determined for each question. Then, the relationship between the levels identified in the first stage was compared. The results will therefore be discussed using three themes: *Students' achievement level in defining energy, students' achievement level in drawing graphs, and the relationship between these levels* (defining the concept and drawing graphs).

Students' Achievement Level in Defining the Energy Concept

Table 1 summarises the general results obtained for the levels of students in the different groups, and shows that a significant number of student answers given to the question regarding the definition of energy is at the level of sound understanding (79, 78, and 55% for each group, respectively). Students' answers classified in terms of sound understanding are similar for all three groups:

“Energy is the ability to do work” (BE Student)

“Energy is defined as the ability to do work” (PE Student)

“The ability to do work is called energy” (EXP Student)

Table 1 also indicates that the remaining responses of the EXP group students are at level [0] Non Understanding and [1] Alternative Conception (14, 7%, respectively). Furthermore, it shows that there were no answers at the [3] Partial Understanding and [2] Partial Understanding with Specific Alternative Conception levels in this group. The distribution of the PE group answers (except for sound

Table 1 Percentage distribution of students’ answers according to level

Natural language representation (%) (F)				Graphic representation (%) (F)							
				Graphics (E_p, E_k, E_T) versus height				Graphics (E_p, E_k, E_T) versus velocity			
Levels	EXP	PE	BE	Levels	EXP	PE	BE	Levels	EXP	PE	BE
[0] NU	14 (2)	7 (5)	20 (32)	[0] ND	–	–	13 (21)	[0] ND	7 (1)	–	17 (27)
[1] AC	7 (1)	4 (3)	15 (24)	[1] IG	29 (4)	38 (26)	23 (36)	[1] IG	79 (11)	80 (55)	82 (132)
[2] PU/AC	–	9 (6)	6 (9)	[2] CG/IGs	50 (7)	16 (11)	23 (36)	[2] CG/IGs	14 (2)	2 (2)	–
[3] PU	–	2 (1)	4 (6)	[3] CGs/IG	–	24 (17)	29 (47)	[3] CGs/IG	–	9 (6)	1 (1)
[4] SU	79 (11)	78 (54)	55 (89)	[4] CG	21 (3)	22 (15)	12 (20)	[4] CG	–	9 (6)	–

understanding level) shows that the response rates at these levels are significantly lower (2, 9, 4 and 7%, respectively).

However, the distribution of the BE group’s responses with level showed that a response rates of level [4] (55%) is closely followed by response rates at levels [0] and [1] (20 and 15%, respectively). Table 1 illustrates that the other answers of this group are at the level of Partial Understanding with Specific Alternative Conception and Partial Understanding (6 and 4%, respectively).

The analysis of the answers given by a significant proportion of the students from the different groups and classified at level [4] indicates that all these students have a common understanding of the definition of the energy concept. This suggests that for a significant number of students from the BE, high school group through to the EXP, postgraduate group, energy means “ability to do work”. It may also be seen in Table 1 that some students from different groups have alternative conceptions. These are shown in Table 2. Analysis of the data in Table 2 reveals that the most frequently encountered alternative conception of energy is “the work done in unit of time”. This shows that students often confuse the concepts of energy and power and use them interchangeably.

Furthermore, Table 2 shows that “Work change on an object” appears as an alternative conception for some students in the EXP and PE groups, and that students in the BE group have different alternative conceptions.

Table 2 Students’ alternative conceptions related to the energy concept

Some definitions given by students	EXP	PE	BE
Work done in a unit of time	X	X	X
Work change on an object	X	X	
Applying power or work on something			X
Applying a force on an object and its displacement as a result of this force			X
Work which comes out is called as energy			X
Force required to do work			X

Students’ Achievement in Drawing Energy Graphs

Students’ achievement in graphical representation is summarised for the different groups in Table 1. Furthermore, some of the graphs drawn more frequently by students are summarised in Table 3.

In order to allow easier interpretation of the results, the graphs of potential energy, kinetic energy, and total energy versus height and those versus velocity will be analysed separately.

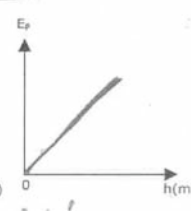
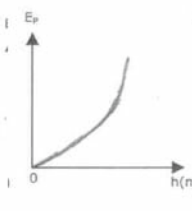
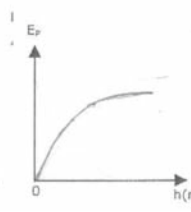
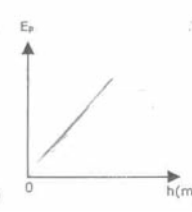
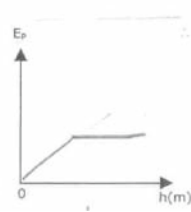
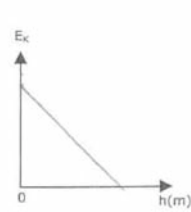
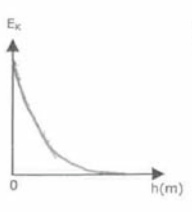
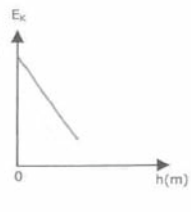
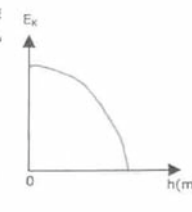
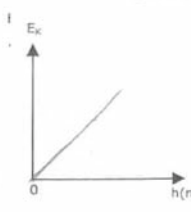
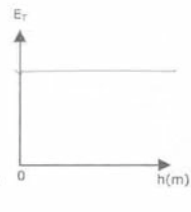
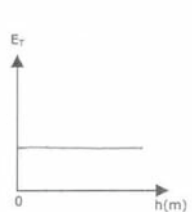
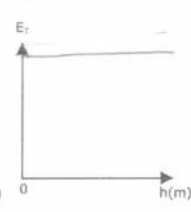
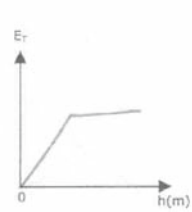
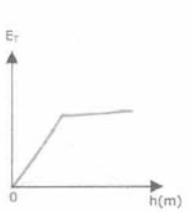
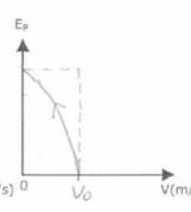
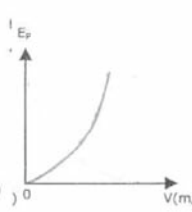
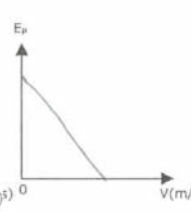
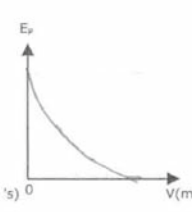
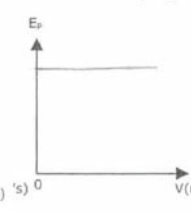
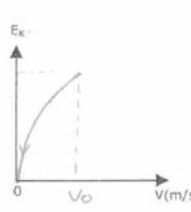
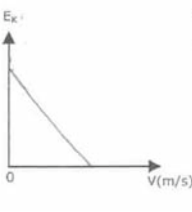
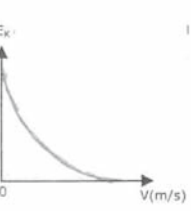
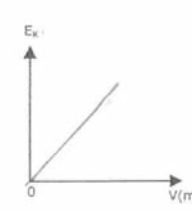
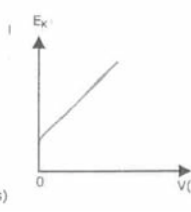
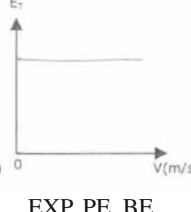
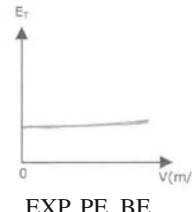
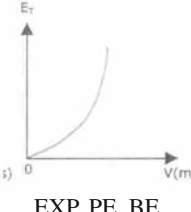
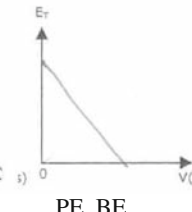
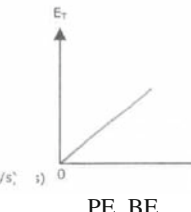
The graphs versus height (drawing a graph using the expression $E_p = m \cdot g \cdot h$)

Table 1 shows that those graphs drawn by students to represent the potential, kinetic and total energy of the related object versus height vary depending on the student group. This table shows that half of the EXP group drew the graph of potential energy (which is directly related to the given equation) correctly, but they failed to draw the two other graphs correctly, and were therefore classified at level [2]. Some of the other students in this group could not draw any of the required graphs correctly and were classified at level [1], while the rest drew all three graphs correctly and were classified at level [4] (29 and 21%, respectively).

In a similar way to the EXP group, Table 1 illustrates that only 22% of the PE group drew the required graphs (level [4]) correctly, and a significant proportion (38%) failed to draw the graphs correctly and were classified at level [1]. Furthermore, some of the remaining PE group students (24%) drew the graph of potential energy directly related to the equation $E_p = m \cdot g \cdot h$ with at least one of the other graphs correctly and were classified at level [3], while the other students (16%) could only successfully draw the graph of potential energy and were considered to be at level [2].

The distribution of the responses given by the BE group shows significant differences compared to the two other groups (Table 1). For example, the number of students who drew all the graphs correctly was significantly lower (EXP 21%, PE 22%, BE 12%), while the number of students who had not drawn any graph at all was higher (0, 0, 13%,

Table 3 Examples of graphs drawn by students

		Correct graphs	Graph I	Graph II	Graph III	Graph IV
The graphics versus height	E_p versus h	 EXP, PE, BE	 EXP, PE, BE	 PE, BE	 EXP, PE	 BE
	E_k versus h	 EXP, PE, BE	 EXP, PE, BE	 EXP, PE, BE	 EXP, PE	 BE
	E_r versus h	 EXP, PE, BE	 EXP, PE, BE	 EXP, PE, BE	 BE	 BE
The graphics versus velocity	E_p versus V	 PE	 EXP, PE, BE	 EXP, PE, BE	 PE, BE	 BE
	E_k versus V	 EXP, PE, BE	 EXP, PE, BE	 EXP, PE, BE	 EXP, PE, BE	 BE
	E_r versus V	 EXP, PE, BE	 EXP, PE, BE	 EXP, PE, BE	 PE, BE	 PE, BE

The table above indicates the group in which the respective graph appeared (i.e. EXP, PE, BE)

respectively). Furthermore, Table 1 illustrates that a significant number of the students in this group (29%) drew at least one of the other graphs together with the graph directly related to the given equation and they were classified at level [3]. However, 23% of the students could only draw correctly the graph of the potential energy directly related to the given equation and were classified at level [2], while the other 23% drew all the graphs incorrectly and were classified at level [1] (Table 1).

The graphs versus velocity (drawing a graph using the expression $E_K = \frac{1}{2}m \cdot V^2$)

The distribution of the graphs drawn by the students according to level using the equation $E_K = \frac{1}{2}m \cdot V^2$ is summarised in Table 1 (graphs of the variation of kinetic, potential and total energy of the object in the system against velocity). The results suggest that a significant proportion of the students in all three groups experienced difficulties drawing the graphs required in this problem (79, 80, 82%, respectively). These results at level [1] demonstrate that levels of achievement in the question on drawing graphs of energy versus velocity were significantly lower than those for the graphs of energy versus height. These lower levels of achievement may be ascribed to the difficulty of interpretation of the direct proportional relationship between the kinetic energy and the square of the velocity in $E_K = \frac{1}{2}m \cdot V^2$. It may therefore be said that students in each of the three groups found difficulty in reproducing this relationship in graphical form.

It may be seen from Table 1 that in the EXP group the 79% score at level [1] is followed by levels [2] and [0] (14 and 7%, respectively). This shows that only 14% of students in the EXP group correctly drew the graph of kinetic energy directly related to the equation $E_K = \frac{1}{2}m \cdot V^2$, while 7% of them were unable to draw any of the graphs.

Furthermore, Table 1 shows that 80% of the graphs were classified at level [1] for the PE group, followed by 9% at level [4] (three graphs drawn correctly) and 9% at level [3]. In addition, 2% of the students in this group correctly drew only the graph of kinetic energy and were classified at level [2].

Finally, the distribution of BE group with respect to their achievement level (Table 1) reveals that 82% of this group were classified at level [1] followed by 17% at level [0] and 1% at level [3]. Therefore, only 1% of the BE students correctly drew the graph of kinetic energy based on the equation $E_K = \frac{1}{2}m \cdot V^2$ and one of the other two graphs, while the remaining students could not draw the required graphs.

By analysing the graphs shown in Table 3, it may be seen that students at different levels drew similar graphs and often made similar mistakes. For example, some students in the different groups had correctly determined that the total energy of the object in the system given was

constant, but replied incorrectly to the question on the graphical representation by drawing it with lower values (E_T vs. h —Graph I) or higher values (E_T vs. h —Graph II) than they should have done.

Furthermore, it may be seen that in order to represent the change in potential and kinetic energy versus height, the students drew various graphs, which had similar characteristics to the correct graphs (i.e. increasing E_P vs. h —Graph I, II, III, IV or decreasing E_K vs. h —Graph I, II, III). However, it was found that in order to represent the change of potential and kinetic energy versus velocity, they drew graphs different from those expected (for example, E_P vs. V —Graph II, IV or E_K vs. V —Graph I, II, III).

Relationship Between the Students' Achievement in Defining Energy and Drawing Graphs

By analysing the answers given to the definition question, it was found that a considerable proportion of students in all three groups gave correct definitions and provided answers at sound levels of understanding (Table 1). However, the same table also illustrates that the achievement levels of these students in questions on graphical representation declined. Table 4 shows the relationship between the students' achievement in defining the energy concept and their ability to draw energy graphs. In constructing Table 4, the levels in the defining question were taken as a reference point to determine levels for graphical questions. In other words, students' levels of achievement in graphical questions were determined with respect to their levels on the NL representation question (defining energy).

Table 4 shows that the individual achievement of students differed between the definition question and graphical questions. For example, 11 students in the EXP group, who gave a definition at the sound understanding level, gave responses classified at different levels for questions on drawing graphs. Accordingly, the achievement level of a significant number (8 out of 11) of these students declined when drawing graphs of variation with height, while all achievement levels declined when drawing graphs of variation with velocity. Likewise, it may be seen that the levels of 54 students in the PE group who gave responses to the definition question at the sound understanding level scored less well in questions in which they were required to draw graphs (Table 4). In a similar way to these two groups, it can be seen that the levels of the BE group who gave responses at the sound understanding level fell significantly, particularly when drawing graphs of variation with velocity, and almost all of these students gave responses at levels 0 and 1. These findings demonstrate that there was no positive correlation between levels of achievement in definition and graphical representation.

Table 4 Relationship between the ability to define energy and draw graphs

Experts				Preexperts				Beginners			
Definition level/ <i>F</i>	<i>h</i>	<i>V</i>		Definition level/ <i>F</i>	<i>h</i>	<i>V</i>		Definition level/ <i>F</i>	<i>h</i>	<i>V</i>	
[0]/2	[0]	–	1	[0]/5	[0]	–		[0]/32	[0]	5	6
	[1]	–	1		[1]	3	3		[1]	2	26
	[2]	2	–		[2]		1		[2]	9	
	[3]	–	–		[3]				[3]	9	
	[4]	–	–		[4]	2	1		[4]	7	
[1]/1	[0]	–	–	[1]/3	[0]			[1]/24	[0]	5	5
	[1]	1	–		[1]	2	2		[1]	6	19
	[2]	–	1		[2]				[2]	6	
	[3]	–	–		[3]				[3]	6	
	[4]	–	–		[4]	1	1		[4]	1	
[2]/0	[0]	–	–	[2]/6	[0]			[2]/9	[0]	3	2
	[1]	–	–		[1]	1	6		[1]		6
	[2]	–	–		[2]	3			[2]	3	
	[3]	–	–		[3]				[3]	3	1
	[4]	–	–		[4]	2			[4]		
[3]/0	[0]	–	–	[3]/1	[0]			[3]/6	[0]	1	1
	[1]	–	–		[1]		1		[1]		5
	[2]	–	–		[2]				[2]		
	[3]	–	–		[3]				[3]	4	
	[4]	–	–		[4]	1			[4]	1	
[4]/11	[0]	–	–	[4]/54	[0]			[4]/89	[0]	7	13
	[1]	3	10		[1]	20	43		[1]	28	76
	[2]	5	1		[2]	8	1		[2]	19	
	[3]	–	–		[3]	17	6		[3]	25	
	[4]	3	–		[4]	9	4		[4]	10	

Furthermore, by examining the status of students classified at different levels for the definition question (other than at the sound understanding level), it may be seen that their achievement levels on graphical representation questions is commonly low whatever their level in the definition question. This indicates that the well known and constantly repeated definition of “*energy is the ability to do work*” was successfully adopted by students, while simple graphical drawing on the same subject was not, and that students’ learning in this regard was therefore one-way.

Discussion and Conclusion

In this study, the conceptual development of students from different educational levels regarding the concept of energy was examined using their responses with natural language and graphical representations of this concept.

Students’ written responses show that the definition “*energy is the ability to do work*” (Warren 1982), which is thought not to be adequate to explain the energy concept completely (Kemp 1984; Diakidoy et al. 2003), is the only

correct definition adopted by students at different levels. Students’ tendency to use this definition can be explained in the light of the reality that the energy concept has an abstract and theoretical structure, and it is therefore considered difficult to understand conceptually (Elkana 1974; Sefton 2004). Another reason for this tendency is students’ idea that “energy is a material used only by living and/or moving objects” (Brook and Wells 1988; Kurnaz 2007). Answers given to the definition question also show that all participants at different levels have alternative conceptions of the energy concept. This result seems to be consistent with that found in the literature (Duit 1984; Goldring and Osborne 1994; Trumper 1998; Gürdal et al. 1999; Kurnaz 2007; Küçük et al. 2005; Ünal Çoban et al. 2007), which says that students develop various alternative conceptions of the concept of energy. Furthermore, the data obtained shows that alternative conceptions about energy are more likely to be both present and varied in beginner students than pre-expert and expert ones. According to the Anthropological Theory, this result may be interpreted as follows: unlike pre-experts and experts, students at beginner level fail to establish a link between the didactic choices,

differences of various institutions (such as daily life, physics, biology, etc.) in which the energy concept is commonly discussed. For this reason, their alternative conceptions are numerous and varied. It may therefore be said that the level of an institution has a positive influence on the construction of a scientific definition of energy.

In recognition of the importance of the different representations of the conceptualisation process of a concept by learners (Hiebert and Carpenter 1992; Duval 1995; Piez and Voxman 1997; Even 1998; Hitt 2002), and the relationship between a student's level of ability to use these representations and his/her learning (Duval 1995), both the graphic representation abilities of students and their definition (natural language representation) abilities were analysed in this study. In this context, when the graphs drawn by students at the different levels were analysed, it was found out that expert and pre-expert group students were more successful than those in the beginner group, but their graphs were still not up to the required standard. This result showed that students at all levels experienced difficulties in visualisation. This finding supports the results of previous studies focusing on students' visualisation problems (Bishop 1980; Dreyfus 1991; Arcavi 2003; Presmeg 2006; Trigueros and Martínez-Planell 2009). More specifically, when the graphs drawn by students were examined in order to characterise students' difficulties in visualisation using graphs, we encountered "the difficulty related to analyzing the relationship between different variables" that was also noted by other previous studies (Hitt 1998; Tairab and Al-Naqbi 2004). Because this difficulty was apparent in the work of students of different grades, the Anthropological Theory would seem to suggest that the level of the institution had no positive influence on removing visualisation difficulties in the representation of energy using graphs. In view of this fact, the use of graphs to teach the energy concept is strongly recommended, because this constitutes an important tool in physics education (Dimitriadis et al. 1999; Van Den Berg et al. 2000).

Furthermore, Table 4, which was produced in order to assess the correlations between our various results, demonstrates that a linear relationship between definition level and graphical representation level does not exist. Accordingly, although a significant proportion of the students used a common definition of energy such as the "ability to do work", and although this concept was correctly defined by them, it may be said that they experience one-way learning of this concept. Thus, the results of this study of the energy concept from a different perspective support those studies that emphasise the difficulties in learning the concept of energy (Warren 1983; Watts 1983; Boyes and Stanisstreet 1990; Trumper 1998; Meltzer 2004; Küçük et al. 2005; Domenech et al. 2007; Kurnaz 2007; Hırça et al. 2008).

When the findings summarised above are evaluated in the context of the learning development (i.e. the conceptual development) of the concept of energy according to student level, two fundamental results are obtained. Teaching at different levels has not enabled students to develop an autonomous definition that is independent of the disciplines of the energy concept, but has had a positive effect on the internalisation of the known definition. This shows that there are significant similarities between students' learning at different levels. Indeed, students from all three groups defined energy in similar ways and possess similar alternative conceptions. On the other hand, it was found that students made no significant progress in graphical representation commensurate with their learning levels. Students often correctly drew the same kinds of graphs (graphs of variation with height) while making mistakes in graphs that were more difficult (graphs of variation with velocity), and also drew similarly incorrect graphs.

References

- Abraham MR, Williamson VM, Wetsbrook SL (1994) A cross-age study of the understanding of five chemistry concepts. *J Res Sci Teach* 31(2):147–165
- Arcavi A (2003) The role of visual representations in the learning of mathematics. *Educ Stud Math* 52(3):215–241
- Bishop AJ (1980) Spatial abilities and mathematics education: a review. *Educ Stud Math* 11(3):257–269
- Boyes E, Stanisstreet M (1990) Pupils' ideas concerning energy sources. *Int Sci Educ* 12(5):513–529
- Brook AJ, Wells P (1988) Conserving the circus? An alternative approach to teaching and learning about energy. *Phys Educ* 23(2):80–85
- Bui Thi KH (2005) Une étude didactique de la vie de l'énergie dans l'enseignement de la Physique, en France et au Vietnam: Des décalages entre savoirs à enseigner au Lycée et savoirs de la formation universitaire, peuvent-ils être source de difficultés pour les enseignants? Unpublished PhD dissertation. University of Joseph Fourier, Grenoble, France
- Çalık M, Ayas A (2005) A comparison of level of understanding of grade 8 students and science student teachers related to selected chemistry concepts. *J Res Sci Teach* 42(6):638–667
- Chevallard Y (1989) Le concept de rapport au savoir. Rapport personnel, rapport institutionnel, rapport officiel. Actes du séminaire de Didactique des Mathématiques et de l'Informatique année 1988-1989, LSD-IMAG, Grenoble, 211–236
- Diakidoy IAN, Kendeou P, Ioannides C (2003) Reading about energy: the effects of text structure in science learning and conceptual change. *Contemp Educ Psychol* 28(3):335–356
- Dimitriadis P, Kabouris K, Karanikas J, Papamichalis K, Papatsimba L, Kalkanis G (1999) Linear motion study through graphs a new technology-based learning environment. In: Proceedings of the 2nd international conference of the European Science Education Research, Kiel 31 August–4 September, 36–38
- Domenech JL, Gil-perez D, Gras-marti A, Guisasola J, Torregrosa JM, Salinas J, Trumper R, Valdes P, Vilches A (2007) Teaching of energy issues: a debate proposal for a global reorientation. *Sci Educ* 16(1):43–64

- Dreyfus T (1991) On the status of visual reasoning in mathematics and mathematics education. In: Furinghetti F (ed) Proceedings of the 15th conference of the International Group for the Psychology of Mathematics Education. Università di Genova, Genova, pp 33–48
- Duit R (1984) Learning to the energy concept in school—empirical results from the Philippines and West Germany. *Phys Educ* 19(2):59–66
- Duit R (1987) Should energy be illustrated as something quasi-material? *Int J Sci Educ* 9(2):139–145
- Duval R (1993) Registres de représentation sémiotique et fonctionnement cognitif de la pensée. *Annales de Didactique et de Sciences Cognitives- IREM de Strasbourg* 5:37–65
- Duval R (1995) *Sémiosis et pensée humaine. Registres sémiotiques et apprentissages intellectuels*. Peter Lang, Berne
- Elkana Y (1974) *The discovery of the conservation of the energy*. Hutchinson, London
- Even R (1998) Factors involved in linking representations of functions. *J Math Behav* 17(1):105–121
- Fry M, Dimeo L, Wilson C, Sadler J, Fawns R (2003) A new approach to teaching ‘energy and change’: using an abstract picture language to teach thermodynamic thinking in junior science classes. *Aust Sci Teach J* 49(1):36–43
- Goldring H, Osborne J (1994) Students’ difficulties with energy and related concepts. *Phys Educ* 29(1):26–32
- Gürdal A, Şahin F, Bayram H (1999) İlköğretim öğretmen adaylarının enerji konusunda bütünlüğü sağlama ve ilişki kurma düzeyleri üzerine bir araştırma. *Dokuz Eylül University. J Buca Fac Educ* 10:382–395
- Haidar HA, Abraham MR (1991) A comparison of applied and theoretical knowledge of concept based on the particulate nature of matter. *J Res Sci Teach* 28(10):919–938
- Heuvelen AV, Zou X (2001) Multiple representations of work-energy processes. *Am J Phys* 69(2):184–194
- Hiebert J, Carpenter T (1992) Learning and teaching with understanding. In: Grouws DA (ed) *Handbook of Research on Mathematics Teaching and Learning*. Macmillan, New York, pp 65–97
- Hırça N, Çalık M, Akdeniz F (2008) Investigating grade 8 students’ conceptions of ‘energy’ and related concepts. *J Turk Sci Educ* 5(1):75–87
- Hitt F (1998) Difficulties in the articulation of different representations linked to the concept of function. *J Math Behav* 17(1):123–134
- Hitt F (2002) *Representations and mathematics visualization*. Cinvestav-IPN, Mexico
- Huis C, Berg E (1993) Teaching energy: a systems approach. *Phys Educ* 28(3):147–153
- Kaper WH, Goedhart MJ (2002) Forms of energy, an intermediary language on the road to thermodynamics? Part I. *Int J Sci Educ* 24(1):81–95
- Kemp HR (1984) The concept of energy without heat or work. *Phys Educ* 19(5):234–240
- Köse S, Bağ H, Sürücü A, Uçak E (2006) Fen bilgisi öğretmen adaylarının canlılardaki enerji kaynaklarıyla ilgili görüşleri. *Int J Envir Sci Educ* 1(2):141–152
- Kruger C, Palacio D, Summers M (1992) Surveys of English primary school teachers’ conceptions of force, energy and materials. *Sci Educ* 76(4):339–351
- Küçük M, Çepni S, Gökdere M (2005) Turkish primary school students’ alternative conceptions about work, power and energy. *J Phys Teach Educ* 3(2):22–28
- Kurnaz MA (2007) *Üniversite 1. sınıf seviyesinde enerji kavramının öğrenim durumlarının analizi*. Unpublished master’s dissertation, Karadeniz Technical University, Trabzon, Turkey
- Kurnaz MA, Sağlam Arslan A (2009) Using the anthropological theory of didactics in physics: characterization of the teaching conditions of energy concept and the personal relations of freshmen to this concept. *J Turk Sci Educ* 6(1):72–88
- Lemmer M, Lemmer TN (2006) The role and place of energy in the physics curriculum. Paper presented at the GIREP 2006 conference: Modeling in Physics and Phys Educ, 20–25 Aug 2006, Amsterdam
- Meltzer DE (2004) Investigation of students’ reasoning regarding heat, work, and the first law of thermodynamics in an introductory calculus-based general physics course. *Am J Phys* 72(11):1432–1446
- Morgil I, Yoruk N (2006) Cross age study of the understanding of some concepts in chemistry subjects in science curriculum. *J Turk Sci Educ* 3(1):15–27
- Nicholls G, Ogborn J (1993) Dimensions of children’s conceptions of energy. *Int J Sci Educ* 15(1):73–81
- Papadouris N, Constantinou CP (2006) Design, development and validation of a teaching proposal for energy: results from a pilot implementation. Paper presented at the GIREP 2006 conference: Modeling in Physics and Phys Educ, 20–25 August 2006, Amsterdam
- Papadouris N, Constantinou CP, Kyratsi T (2008) Students’ use of the energy model to account for changes in physical systems. *J Res Sci Teach* 45(4):444–469
- Pell T, Jarvis T (2001) Developing attitude to science scales for use with children of ages from five to eleven years. *Int J Sci Educ* 23(8):847–862
- Piez CM, Voxman MH (1997) Multiple representations-using different perspectives to form a clearer picture. *Math Teach* 90(2):164–166
- Presmeg NC (2006) Research on visualization in learning and teaching mathematics. In: Gutiérrez A, Boero P (eds) *Handbook of research on the psychology of mathematics education: Past present and future*. Sense, Rotterdam, pp 205–235
- Rowlands S, Graham T, Berry J, McWilliams P (2007) Conceptual change through the lens of Newtonian mechanics. *Sci Educ* 16(1):21–42
- Saka A, Cerrah L, Akdeniz AR, Ayas A (2006) A cross-age study of the understanding of three genetic concepts: how do they image the gene, DNA and chromosome? *J Sci Educ Technol* 15(2):192–202
- Sefton I (2004) Understanding energy. In: Proceedings of 11th biennial science teachers’ Workshop, 17–18 June 2004, University of Sydney
- Séjourné A, Tiberghien A (2001) Conception d’un hypermédia en physique et études des activités des élèves du point de vue de l’apprentissage. *Actes du Cinquième Colloque Hypermédiat et Apprentissages*, Grenoble
- Tairab HH, Al-Naqbi AK (2004) How do secondary school science students interpret and construct scientific graphs? *J Biol Educ* 38(3):127–132
- Trigueros M, Martínez-Planell R (2009) Geometrical representations in the learning of two-variable functions. *Educ Stud Math*, Published online 24 June 2009
- Trowbridge JE, Mintzes JJ (1988) Alternative conceptions in animal classification: a cross-age study. *J Res Sci Teach* 25(7):547–571
- Trumper R (1990) Being constructive: an alternative approach to the teaching of the energy concept, part one. *Int J Sci Educ* 12(4):343–354
- Trumper R (1991) Being constructive: an alternative approach to the teaching of the energy concept, part two. *Int J Sci Educ* 13(1):1–10
- Trumper R (1998) A longitudinal study of physics students’ conceptions on energy in pre-service training for high school teachers. *J Sci Educ Technol* 7(4):311–318
- Trumper R, Gorsky P (1993) Learning about energy: the influence of alternative frameworks, cognitive levels, and closed-mindedness. *J Res Sci Teach* 30(7):637–648

- Ünal Çoban G, Aktamış H, Ergin Ö (2007) İlköğretim 8. Sınıf Öğrencilerinin Enerjiyle İlgili Görüşleri. Gazi University. J Kastamonu Fac Educ 15(1):175–184
- Van Den Berg E, Van Den Berg R, Capistrano N, Sicam A (2000) Kinematics graphs and instant feedback. Sch Sci Rev 82:104–107
- Warren JW (1982) The nature of energy. Eur J Sci Educ 4(3):295–297
- Warren JW (1983) Energy and its carriers: a critical analysis. Phys Educ 18(5):209–212
- Watts DM (1983) Some alternative views on energy. Phys Educ 18(5):213–217
- Westbrook SL, Marek EA (1992) A cross-age study of student understanding of the concept of homeostasis. J Res Sci Teach 29(1):51–61