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Misconceptions on classical mechanics by freshman university students: A case study in a Physics Department in Greece

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Abstract

This paper presents results of an empirical research study on Newton's laws classical mechanics and its perceptions on freshman students at the Physics Department, University of Ioannina, Greece. Results and outcome measures reveal misconceptions on students' perceptions in consideration of the fundamental concepts in freshman Physics education. The findings showed that the students continue to have the same misconceptions on concepts, such as the students of the high school. The research indicates that the students' misconceptions remain largely throughout secondary education, which is a proof that there is no effort, where appropriate for conceptual change, according to the constructive model of learning and teaching physics. The objective intended to be reached in this communication is to provide an exchange forum of ideas that would help instructors originate the cause, and subsequently avoid misconceptions in freshman Physics education.

Introduction

In the last decades systematic efforts have been introduced in consideration of Physics education improvement. During the late 1970s, the view of learning was shifted from the classical behaviourist model towards to a more constructivist perspective that emphasizes on the students' active role during the learning process (Duit & Treagust, 1998; Mason, 2003). This perspective originated by the consciousness that constructivist ways of Physics teaching help students in acquiring scientific ways of thinking. This alternative provides to the students the ability of taking decisions for difficult and/or complex situations and subsequently, achieving their purpose with reference to time and space requirements that are associated to the progress of modern societies. In general, science education is addressed to provide a sufficient illustration of the world in which we live, while it contributes to the informed decisions needed for ensuring sustainability between future development and lifestyles. A sustainable future requires feedback from communities that are aware of how science informs our thinking and empowers our ability to proceed to informed decisions (Murcia, 2008). Tytler and Symington (2006) observed that science teaching and learning reflects science operation in the community, and considered its existence within economical, political and societal contexts.

Despite the appropriate performance of traditional science courses, numerous studies reveal students' difficulties in understanding the basic concepts of Physics (Trowbridge & McDermott, 1980; 1981; Halloun & Hestenes, 1985; Pfundt & Duit, 2000). Those difficulties, regularly incompatible with scientific theories and knowledge, are referred as misconceptions or alternative conceptions. Their conceptions for the physical phenomena possess universality and help them to constitute interpretative models while they refer to the various physical events with alternative names, impulsive understandings, misperceptions etc. The students form their perception through the interaction with their natural and social environment, while attempting to employ theories in order to understand the world they live in; for example, to understand a phenomenon or to predict a natural event. These students' conceptions are consistent across diverse samples, are resisted to changes, and influence further learning. Thus, many students retain the same misconceptions even after the completion of the course (e.g. Gunstone, 1987; Driver, 1989; Reif, 1995; McDermott & Redish, 1999, Hung & Jonassen, 2006; Senocak, 2006).

According to Redish (1994), rapid technological changes entail radical changes in science teaching: *'It asks us to focus less on what we are teaching, and more on what our students are learning'.* Moreover, McDermott (1998) expresses her worry about the traditional way of Physics teaching as it is well known that students have serious difficulties in understanding the basics laws of Physics and apply them in real situations, even at University level (Guisasola et al., 2002; Kotsis, 2002; Maloney et al., 2001; Yalcin et al., 2008; Thorn & Gunstone, 2007; Gustafson & Rowell, 1995; Kelly, 2000; Appleton, 1995; Libarkin et al., 2005; Gonen, 2008). Halloun (1998) identically observes that students who attend an elective science course are unable to make a distinction among different concepts, as well as to apply them to real world situations.

The present work traces misconceptions of classical mechanics concepts in freshman undergraduate education at Physics Department and proposes guidelines that could be found assistive to tutors. Mechanics is not merely a domain of physics that shares its place amongst other domains, such as light, sound, heat, electricity, etc. Rather, these domains are structured by mechanics in the sense that, without the laws of motion there would be no kinetic theory of gases or no electromagnetic theory, for example (Carson & Rowlands, 2005). Galili (1995), reporting on the way student conceptions in electromagnetism were influenced by prior conceptions of force and motion, states: *"Physics is known as being an especially 'fertile soil' for students' misconceptions. A huge edifice, which today we call physics, consists of various domains. The importance of mechanics is more than just being one of these domains. It determines the 'rules of the game', defines the main tools in physics, and presents the most universal laws of nature. It actually describes the method of the discipline of physics which is then applied in all other domains in this discipline. This is why mechanics always opens any physics curriculum".* Also, the concepts of weight, force and mass are among the most fundamental physical notions that essentially affecting general physics knowledge (Galili, 2001). It is widely accepted that the way students comprehend and involve with basic scientific concepts ultimately predetermines their success in the science learning process (McDermott, 1984). The constructivist approach to the science teaching-learning process supports this claim and elucidates the way students develop new knowledge. (Driver, 1981; Driver et al., 1985; von Glasersfeld, 1991).

The research

101 first year students (69 male and 32 female) of the Physics Department of Ioannina University in Greece, participated in this research. The sample represents the 70% of the total number of the first year students in Greek Physics Departments. We select our sample randomly and the tool used was a closed type questionnaire. For the research we don't use known popular standardised multiple-choice test, like the Force Concept Inventory (FCI) (Hestenes et al. 1992) or Force and Motion Concept Evaluation (FMCE) (Thornton and Sokoloff 1998), or the Mechanics Baseline Test (MBT) (Hestenes & Wells 1992b), to assess students' conceptions and beliefs. We prefer to use simple questions that presented below, to found out the University students' misconceptions. The questions were related to simple physical phenomena of every day life, therefore avoiding questions that are often used to check typical knowledge of the students. The questionnaire was distributed to the students at the beginning of the Academic year 2005-2006. According to the Greek Educational sys-

tem, a student can go from high school to University after exams. To enter the Physics Department someone has to succeed the exams in a National level, at two physics courses. All the students had formal education in physics at the high school for more than three years.

Results and Discussion

In the following we give the obtained results gathered in groups according to the physical laws or concepts for which one or more questions were used.

First Newton's law

The purpose of these questions was to reveal the perception of the students concerning the role of the forces acting on a body when the last one is moving with constant velocity or it is at rest.

Question 1: *"The fact that a book remains in rest, when put on a table is due to…"*

The results presented in Table 1 show that the majority of the students (89%) recognize correctly that the reason for a body to be at rest is that the total force acting on it equals zero.

Table 1. Students' answers to question 1

Answer	Percentage (%) N=101
Gravity	2
The total force on the book is equal to zero	89
The table stops the book to fall down	9

Question 2: *"A car is moving on a straight road with constant velocity. The sum of the forces acting on it…"*

From these results, we can notice that 22% of the students are thinking according to the Aristotelian physics for a motion with a constant velocity. They consider as due to a constant force acts on the body having the same direction with its velocity. Al

Table 2. Students' answers to question 2

Answer	Percentage (%) N=101
Has the speed direction	22
Depends from the speed value	1
Is zero	69
Is equal with weight of the car	2
Depends from the mass of the car	6

though Aristotle's physics was qualitative, and he did not present any formulations of his assertions, it is stated that according to Aristotle the speed of an object is proportional to the force exerted on the object. In addition, he thought that when no forces act on an object it comes to rest. The followers of Aristotle stated, in accordance with Aristotle's thoughts that increase in speed is due to increase in force. Similar results have been also reported by Halloun and Hestenes (1985).

Question 3: *"When a car is moving with a constant velocity to the right the total force acting on it, is..."*

Table 3. Students' answers to question 3

Answer	Percentage (%) N=101
Is equal to zero	56
Has a direction to the right	38
Has a direction to the left	6

From the answers to this question, in conjunction to those referring the previous one, there are 38% of the students that preserve the misconception of the meaning of the first Newton's law. This can be attributed to the lack of efforts in obtaining insight of the meaning of this basic law, along with the students built mentally their pictorial representations. In particular, the students imagine the existence of the force acting on the car in the same direction of the constant velocity. Viennot (1979) has argued that there is a tendency in spontaneous reasoning to attribute physical quantities, like force in this case, to objects themselves. Thus, force is considered as a property of a body which keeps it moving. This can be also related to the graphical representations of motion that the tutors are often using when designing the velocity vector on the car for the representation of the situation given in the present question. There are studies (Goldberg & Anderson 1989) which have identified students' difficulties in graphically representing motions of real objects. The relationship between force and motion has been the subject between many invenstigations and studies (Lombardi, 1999; Carson & Rowlands, 2005; Smith & Whittmann, 2008, Jimoyiannis & Komis, 2003). According to Rowlands et al. (2007) "'misconceptions' of force and motion are fundamental because understanding the Newtonian concept of force and motion is essential in understanding the system as a whole".

It seems that conventional study of the force and motion relationship is inadequate to lead students' to conceptualise and organise their knowledge meaningfully: "a force is required only to change momentum" (Jimoyiannis & Komis, 2003).

Second Newton's law

The next questions of the research focused exclusively on the relationship between the mass and the total force acting on a body. The questions used are:

Question 4: *"At the moment the man applies a constant horizontal force on the empty and not moving cart (Figure 1) rain starts falling vertically in it. Which of the following phrases is correctly describing the motion of the cart until this is filled with water, considering that any kinds of friction forces are absent?"*

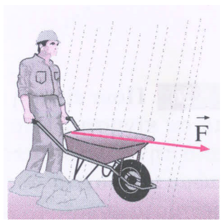

Figure 1.

Table 4. Students' answers to question 4

Answer	Percentage (%) N=101
The cart's acceleration is constant	15
The cart's acceleration is reducing all the time	71
The cart is moving with a constant velocity	14

From the answers given in the histogram it comes out that 14% of the students consider that the application of a constant force results to constant velocity, and 15% results a constant acceleration, neglecting the effect that has to be taken into account from the increase of the mass due to the accumulation of the water.

Question 5: *"Two similar bodies are lying on smooth horizontal surfaces, one on earth and the other on the moon. We want to give to both bodies the same horizontal acceleration. The required force is…"*

Table 5. Students' answers to question 4

Answer	Percentage (%) N=101
The same for the two bodies	27
Bigger in Earth	56
Bigger in Moon	17

The answers in this question are apocalyptic: only 25% of the students gave the right answer, revealing the erroneous perception of the application of the second Newton's law. In addition, there is confusion in the meaning of the weight of a mass considering that the heavier body would be the one on the earth and therefore that force that will be required to accelerate it has to be larger than the one lying on the moon. Moreover, this result indicates that although the students have a rather good perception for the relation of the mass with the weight, when a more complex situation is involved, they fail to combine their knowledge preferring to use instead initiative reasoning.

Third Newton's law

The next questions are referring on the third Newton's law.

Question 6: *"A pot is lying on a table acting a force on it that is directed downwards. The reaction to this force is:"*

From Table 6 we can conclude that a rather large number of the students have a rather good application of the 3rd law; although we have to note that the percentage of incorrect answers cannot be considered as negligible. These results have to be combined with those obtained from the following question.

Table 6. Students' answers to question 6

Answer	Percentage (%) N=101
The force from the Earth to the pot	4
The force from the table to the pot	86
The weight of the pot	10

Question 7: *"The reaction to the weight of the box shown in the next picture is the force acting from…" (Figure 2):*

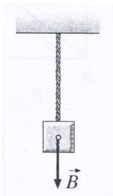

Figure 2.

Table 7. Students' answers to question 7

Answer	Percentage (%) N=101
From the box to the rope	21
From the roof to the rope	4
From the rope to the box	59
From the box to the Earth	16

From the answers we can notice that only 16% of the students give the right answer. Terry and Jones (1986) and Brown (1989) have documented similar difficulties with Newton's third law. This result indicates that although the students know the 3rd Newton's law, as deduced from the previous two questions, they fail to apply it correctly in a realistic situation, like the one given in the picture. In particular, in this picture the earth or the floor is not appearing and therefore the students have a difficulty to make the relation of the weight of the pending body with the reaction force from the body to earth. Brown (1989) has argued that *'the third law should be treated as a much more significant part of an introductory physics course since it is important for developing the students' qualitative concept of force.'*

The next question reveals also the difficulty of the students in combining their knowledge to explain complex situations.

Question 8: *"While you are standing on a balance you pull the laces of your shoes, the indication of the balance will be …"*

Table 8. Students' answers to question 8

Answer	Percentage (%) N=101
Smaller	31
Bigger	27
The same	42

From these answers, that are wrong more than 60%, we conclude that the students have difficulties in analyzing and understanding real every day situations and although they know the 3rd law they fail to apply it correctly. This can be attributed to the mnemonic way of the students that usually acquire their knowledge, a fact that is not only related to the way of teaching but also to the system used for the testing of their knowledge.

Several articles focus particularly on students' understandings of Newton's third law (Terry & Jones, 1986, Brown, 1989, Montanero et al., 2002). The findings commonly indicate that most students have a poor understanding of Newton's third law and of the force concept in general. In the light of such findings it appears that Newton's laws are difficult both to teach and to learn (Savinainen, 2004).

Force

One would expect that Newtonian mechanics would be one of relatively easy chapters of Physics because of its structure and relation with phenomena that are closed to everyday life. However, in practice the students have difficulties that are mainly qualitative and quantitative in understanding the meaning of the various laws. The following question reveals the difficulties in the conception of the meaning of the force.

Question 9: *"A golf ball is moving in the air, as shown in the picture. A student claims that there are three forces acting on the ball: the gravity, B, the force of the knock, F and the force of the air resistance, T. In fact the force on the ball is the sum of…" (Figure 3):*

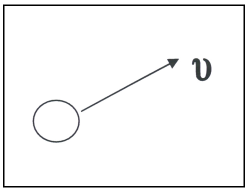

Figure 3.

Table 9. Students' answers to question 9

Answer	Percentage (%) N=101
Only of B	3
Only of B and F	14
Only of B and T	30
Only of B, F and T	42
Only of F and T	11

From these answers we conclude that most of the students correlate the motion of an object with the action of a force in the direction of the movement. The 70% of them include the force of the knock F. The students believe that the force that initiated the motion is still acting on the body and accompanies it in its movement. They believe that the motion implies force and they tend to introduce a non-Newtonian force in the direction of motion (Viennot 1979). This perception is known under the name of "theory of impulsion" (Clement 1982) and it appears to be a common way of thinking in students of many countries (Champagne et al. 1980).

At a more general level, it can be stated that students' understandings of the force concept are very often context dependent, meaning that a student may show correct understanding in some exercises involving the force concept but fail to apply this in other contexts (Bao et al., 2002, Palmer, 1997, Savinainen & Scott, 2002; Steinberg & Sabella, 1997).

Mass-weight

On the following questions we studied the student perception on the meanings of mass and weight.

Question 10: *"A stone is weighted in the surface of the earth and surface. In what place the stone has the bigger weight?"*

Table 10. Students' answers to question 10

Answer	Percentage (%) N=101
The same	3
On Earth	92
On Moon	5

From the answers in this question we could think that the students distinguish the difference between mass and weight. However, when looking at the answers of the next questions we have to have some doubts about this outcome.

Question 11: *"A stone on the earth and another on the moon are weighted and found to have the same weights. Which one of the two stones has the larger mass?"*

Table 11. Students' answers to question 11

Answer	Percentage (%) N=101
The stone on Earth	11
The same	10
The stone on Moon	79

About 20% of the students gave a wrong answer to this question. The situation becomes clearer after the examination of the results of the following question.

Question 12: *"The bucket and the cube shown in the next picture have the same masses but are staying at different heights above the floor. Which one has the bigger weight?" (Figure 4)*

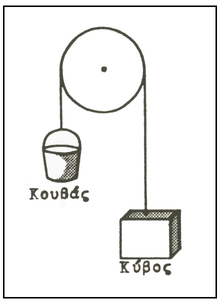

Figure 4.

Table 12. Students' answers to question 12

Answer	Percentage (%) N=101
The same	41
The bucket	18
The cube	41

The situation is a typical case of asymmetric equilibrium in which the sum of the forces acting on the system is zero. However, looking at the results we find that around 59% of the students gave wrong answer.

Apparently the students consider that there is a force acting on the cube having the same "direction" with the image shown in the picture and thus they justify the fact that the cube is lower than the bucket. It appears therefore that they ignore that the two bodies are at equilibrium and they focus only on the visual observation. The investigation of Gunstone and White (1981) which probed students' understanding of gravity noted that many students expressed the belief that two objects with equal masses the one which is closer to the earth is heavier.

Adopting this way of thinking, reasoning based on observable characteristics, a student attempts to reduce the variables that determine the physical problem. He uses each time just one variable, this one that he can observe, or alternatively none if he cannot "see" the result. As a consequence of this way of thinking, if the student does not observe a result, he considers that there is not a reason. The basic characteristics of this way of thinking of the students, i.e. the active force and the result of the action as well as the direction of the action from the active force to the resulting effect, renders difficult the comprehension of the interactions between bodies and therefore the 3^{rd} Newton's law.

In addition, very important role plays also the figure of the text books (Xalkia & Theodoridis, 2002) because the students "believe" in what they are see and not in what it may really happening. Perhaps the greater size of the cube compared to that of the bucket or the fact that the cube is lower from the bucket may have misleaded the students in giving erroneous answers to this last question. The students are based on what they see (Levin et al., 1987) and they are not using critical way of thinking to discover the real situation, an outcome that suggesting the lack of suitable education in developing this way of working instead of the accumulating barren knowledge.

Some studies have shown that not only students but also pre-service teachers (Trumper, 2001) and in-service elementary school teachers (Bulunuz & Jarrett, 2006) have many misconceptions in these areas. Both elementary school and physics teachers need to have expertise to teach the entire science curriculum, including biology, chemistry, physics, and earth and space science concepts at different grade levels. Having a force at a distance and its effects only being felt render gravitational force concept and concepts (Weight, gravitational acceleration, and gravitational mass etc.) related to it difficult to understand (Gonen, 2008). Research findings show that misconceptions are highly resistant to change by traditional interventions (Dahl et al. 2005). The research and on in-service teachers (Bulunuz & Jarrett, 200; Kikas, 2004), shows that they do not have enough scientific understanding about earth and space science concepts generally.

Conclusions

Summarizing we can state that a significant number of the students preserves the misconceptions despite their education in physics in the high school for several years. The results of this study are ın agreement with the results from studies concerning students' conceptions that have apparently shown that they are persistent and resistant to changes, i.e., students hold to their beliefs firmly, and it is very difficult to change them by instruction (Chi et al. 1994; McDermott, 1999). Also it is shown that, the common-sense conceptions are persistent because they are adequate in explaining everyday observations about the physical world (Posner et al., 1982). Extensive research findings point strongly to the conclusion that much of students' apparent learning in science is transitory and does not involve them in developing conceptual understanding. Often students are not aware that they use different conceptions in different contexts, and often their original conceptions are retained long after the science conceptions learned for tests have been forgotten (Brass, 2003). Students' alternative conceptions could be so deeply rooted that traditional instruction may be somewhat inadequate to effect conceptual change toward focused scientific concepts (Cakir et al., 2002). Studies also have shown that even students who achieve high grades often cannot apply basic physical principles to solve problems for realistic situations (Moore, 1999).

Generally speaking, the answers of the questions in this study exhibit two basic characteristics that can be also found in students of all educational levels concerning the perceptions of the physics concepts. The students are based mainly on their own perceptions that have either intuitive or empirical character and also on scientific knowledge acquired from their education resulting in contradictions and confusions.

From the analysis of the results of the present work we can deduce some reasons that are responsible for such misconceptions.

One of them is the abusive use of the everyday language and experience in the interpretation of the physical meanings. The excessive reliance on everyday language should be considered as potential source of misunderstandings (Yalcin, 2008). The words force and weight that are often used in the ordinary language have taken a very precise technical meaning, a fact that is very unusual for the student. They cannot realize that although the words are the same their meanings have been totally revised. Characteristic examples are the confusion between the weight and the mass, as well as the force acting continuously on the golf ball all the way long its trajectory. Dekkers et al. (1998) have discussed the incorrectness of students' conceptions with an example of mechanics. They examined whether the common conception '*motion implies force*' expresses an incorrect belief or does 'force' mean to the students something different than for scientists. The authors point out that the meanings of terms and the conceptions expressed in those terms must be distinguished. Moreover, it should be noted that students' meanings of the words are not necessarily the same as the scientists'. In their research the authors have remarked that for many students 'force' is something a moving object possesses. Thus, students' concept of 'force' is different from the scientists' concept. Dekkers et al. (1998) conclude that this indicates a conceptual problem but not in the sense of an incorrect conception of force.

In addition, a great number of the students' perceptions are originated from the everyday experience concerning the motion, the collisions, the movement of objects resulting in a fortification of these ideas in a large variety of cases, like the case of the two bodies, one on earth and the other on the moon.

Moreover, a lot of students memorize and repeat orally rather well the functional definitions of the various physical meanings, without having the ability of predicting or describing a phenomenon recalling the original scientific thinking. Characteristic example is the motion of a car with constant velocity in a straight road (question 5) and the larger deviation of the correct answers given when the question is altered by introducing the direction of the motion (question 6). From these results it comes also out the mnemonic way of learning and the absence of the critical thinking.

Furthermore, the illustrations existing in the various textbooks seem to have a significant influence in the way the students interpret the scientific knowledge and contribute to the creation of pictorial representations that determine the relations between the various phenomena and the associated physical meanings. The pictures do not act just as decorative elements, but they project messages and affect seriously the mental functioning for the interpretation of these messages. In the cases where a student does not have sufficient amount of optical experiences and the existing knowledge is either mechanistic or wrong, that way he is going to read a picture is not correct and it is going to lead him in erroneous conclusions. As stated by Combrich (1995) "the way we read a picture depends on the amount of the images (optical representations) that are stored in our mind… We are able to recognize only what we know". The case of the bucket and the cube and the difference in the volume of these two objects or their difference in height are some of the most plausible reasons for the great number of wrong answers in the corresponding question. Even in the case of the suspended object (question 7), the students focus on the elements given by the picture, like the box, the rope and the floor or the earth is not shown and therefore there exclude any answer that could be related to the earth.

The concept of interaction, although not always explicitly expressed, was central in the development of Newtonian mechanics. According to the Newtonian view, forces arise from interactions, and a force does not exist except as arising from interaction of two objects (Brown 1989). Newton's theory is constructed to describe the effects of interaction, and the central laws can be seen as laws that enable to make the force a quantity measuring the strength of the interaction. However, it is now customary to introduce the concepts of mechanics essentially in a form of a 'one body problem' removed from the natural context of interaction between two bodies. This may be connected to students' difficulties with symmetry of interaction and Newton's third law. This historical choice is still reflected in many textbook presentations.

In recent years there is a growing research on the application of constructivist method of teaching in the classroom (Duit, 2006). The research in this area shows that applying the principles of constructivism in school practice is influenced by the views of teachers on teaching and learning (Spyrtou et al., 2003). In practise the existing teaching approaches has not the characteristics of a constructive approach (Duit & Treagust, 2003).

The New Physics Curriculum and its directions have not effectively expanded into the Greek schools. It seems that in many cases, teachers still tend to introduce topics in mechanics in a superficial way, where emphasis is given to quantitative problems only (Jimoyiannis & Komis, 2003).

The results of this study indicate that the Greek teacher in high school does not use the constructivist theories to teach their students. The misconceptions are strong even among the Universities students. According to constructivist theories, new conceptions are constructed based on the learner's previous ones. Consequently, the teacher has to be aware of students' previous conceptions in order to enhance the learning process. The teacher's role in learning is to help the learner in constructing the knowledge, e.g., by presenting problems and encouraging the learners to observe, examine, formulate hypotheses, and test them. Constructivist views are optimistic in the sense that they trust the learner's ability to conduct his or hers learning process. Thus, in teaching based on constructivist principles, instead of teacher-centred instruction, the learner's own activity, creativity, and initiative, as well as interaction with other learners, are emphasized while the role of the teacher is becoming less important.

The New Physics Curriculum in Greece aims at promoting students' active engagement by allowing time for identifying, reflecting and thinking about scientific concepts, establishing experimentation in the physics laboratory and the use of physics educational software (Ministry of Education, 1998). But, in most cases, students still favour passively accumulating definitions, equations or facts, while they are hardly practiced in solving conventional quantitative problems (Jimoyiannis & Komis, 2003).

The Greek teacher in high school is still teaching with the traditional way of teacher-centred instruction and he/she does not pay attention to the students' misconceptions. These misconceptions are resistant to change even after the students have received formal physics education. This resistance has been observed in both college students and high school students (Hung & Jonassen, 2006). Restructuring their misconceptions is required for complete and scientific understanding of physics (Nersessian, 1992). Our results also confirm this view. Research findings have suggested that formal traditional, teacher-centred instruction does not help produce conceptual change. (Hammer, 1996; Vosniadou & Ioannides, 1998). According to Vosniadou (1994), the addition of new information to an existing conceptual structure is simple and lead to conceptual change, but unfortunately this does not happen in the Greek high school.

Taking into consideration that the students, who participated in this research, are the students who dealt with the subject of physics, in order to enter in the University, the real picture is much worse from that presented in this paper. Such results are the proofs that there should be a serious effort by all stakeholders of education, in order to use a modern method of teaching physics in secondary education, which has proven that it can make conceptual changes in students' misconceptions. Also in the other hand, the staff of the University Departments should take note of the background of the knowledge of their students before teaching them.

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