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Investigating Greek Students' Ideas about Forces and Motion

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Abstract

Educational research has shown that high school and university students also follow the Aristotelian idea about motion; for example, a continuous action of a force is necessary to keep an object in motion. The survey presented in this article aims at a deeper investigation of secondary education students' ideas about the forces involved in objects moving under the sole influence of gravity. The main objectives are: (1) to investigate other ideas or difficulties, which intervene and determine students' mental models about motion and force, and (2) to reveal how the students in the sample are grouped according to their alternative conceptions. Our study has been mainly determined by the revision in Science Curriculum established in Greece three years ago. A survey has been administered to a total of 146 students (15–16 years old) attending six typical public high schools in Greece. The results presented show that the traditional instruction is pertinent while the approaches of the New Physics Curriculum have not been effectively expanded to the schools. The majority of the students exhibited the idea that "the original force is continuously exerted to the ball during its motion." On the other hand, multivariate analysis has identified three discernible groups of students which have exhibited a persistent and rather consistent approach: (1) An extended group of students having the above misconception, (2) a second group of students which, generally, responded correctly to the tasks, and (3) a third group of students, which ignored the presence of the gravitational force and/or believe that the action-reaction forces are both exerted to the ball during its motion.

Key Words: alternative conceptions, force and motion, physics education

A great deal of research on Physics Education has focused on the study of the alternative conceptions and mental models employed by students before and after instruction (McDermott & Redish, 1999, and references therein). It has been well established by research findings that students possess an incoherent system of beliefs and intuitions about physical phenomena, mainly derived from their everyday experience. Those beliefs and ideas are usually incompatible with scientific theories and knowledge; they have been referred to as misconceptions or alternative conceptions.

Research has further shown that high school and even university students' knowledge consists of a small number of facts and equations that are not effective for the interpretation of simple, real-world physical phenomena. Defective procedural knowledge is often evident in the problem solving approaches employed by most of the students (Van Heuvelen, 1991).

Students' alternative conceptions have been investigated in a wide range of physics domains (McDermott & Redish, 1999). Among these, force and motion have received much interest. Although force is one of the first concepts that students are faced with, their mental models are usually incompatible with the scientific ones. A common secondary students' misconception, which has been independently studied (Enderstein & Spango, 1996; Galili & Bar, 1992; McCloskey, Caramazza, & Green, 1980; Watts & Zylbersztajn, 1981), concerns the motion and force relationship. Different research studies (Halloun & Hestenes, 1985; Whitaker, 1983) have suggested that university students' beliefs about motion in the earth's gravitational field are usually based on Aristotelian ideas derived from limited first-hand experience of real life phenomena.

It has been proven, by research findings, that secondary and university students both follow the Aristotelian idea about motion: "a continuous action of a force is necessary to keep an object in motion." Clement (1982) has found that 75% of a group of engineering students did associate motion with a force in the direction of motion, after one semester of instruction in mechanics. In their study, concerning college students' ideas, Halloun and Hestenes (1985) have developed a taxonomy of common sense concepts about motion.

Different surveys concerning secondary students have independently shown that only a very small proportion, lower that 20%, did not consider the presence of a force in the direction of motion required to sustain that motion (Enderstein & Spango, 1996; McCloskey, Caramazza, & Green, 1980; Salamand & Kess, 1990; Watts & Zylbersztajn, 1981). It has also been found that the above ideas are common across age and culture (Enderstein & Spango, 1996). Galili and Bar (1992) have found that secondary education students were more likely to use the idea "motion implies a force" as the research questions increased in difficulty. On the other hand, Palmer (1997) has shown that scientifically irrelevant contextual features play a large part in determining students' reasoning about force and motion.

Objectives

This study was mainly based on the revision of Science Curriculum, which has been established in Greece about three years ago, in the framework of extended educational changes concerning upper secondary education (Ministry of Education, 1998). Before 1998, physics instruction in Greek secondary schools was restricted to traditional approaches, which consisted of presenting material through lectures in the classroom. In other words, teachers and students conceived physics instruction as a process of information transfer. This approach puts students in a passive role, encourages memorisation rather than active construction of knowledge, and fails to connect teaching material with the students' previous knowledge.

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.

The research presented here has been administered in a period which characterises the transition of physics instruction in Greek secondary education from the traditional to the new teaching approaches. The results presented here are the first ones concerning Greek secondary education students' ideas about motion and force. It is of high scientific interest to compare our results with those of similar research administered in other countries (Enderstein & Spango, 1996; McCloskey, Caramazza, & Green, 1980; Salamand & Kess, 1990; Watts & Zylbersztajn, 1981).

Data already published offer a lot of knowledge but they are restricted to a descriptive survey of students' beliefs about motion and forces. Descriptive analysis of the students' responses shows only their different approaches to the various tasks. To overcome these limitations we have used the method of *Multiple Correspondence Analysis* (Benzécri, 1992; Greenacre, 1993) to analyse further our research data. We chose this type of multivariate analysis because it helps us to obtain an overall view of the students' alternative conceptions and to reveal numerous correlations, across the research tasks, in conjunction with their age, gender, school, social-economic background and other characteristics.

Our multivariate analysis aims at a deeper investigation of students' beliefs concerning motion and force, covering the following directions:

1. Is the belief "motion needs a continuous force" a stable idea or do students display it incidentally?
2. Can we determine other ideas or difficulties that affect students' mental models?
3. How are students grouped according to their alternative conceptions?

Method

The Sample

The survey presented in this article has been administered to six typical public high schools in the city of Ioannina, Greece. A total of 146 students (83 boys and 63 girls) attending the first year of Lyceum[1] (15–16 years old) participated in the research. They have been randomly selected representing a wide range of achievement levels. The students in the sample were from a variety of socio-economic backgrounds.

The Procedure

Our research took place about six months after students had received school teaching on Newton's laws. No educational intervention took place before the research process. Prior to their participation in the research all students had received traditional instruction on these topics in the classroom. Their activities, in the classroom and/or in their homework, were generally restricted to conventional problem solving, mainly based on handling mathematical equations and deriving quantitative results.

Besides conventional instruction, students in 8th Lyceum of Ioannina were further involved in four experimental activities without our intervention. They spent four hours in the physics laboratory performing tasks independently designed by their teacher. They studied kinematics laws (three experimental tasks) and Newton's Second Law (one experimental task).

During students' answering the researcher's role was restricted to elucidating their questions in order to clarify the tasks under study. In order to ensure that the physical processes, the information and the sketches involved in the questionnaire were clearly understood, a trial run of the research was carried out in one of the schools. The trial group consisted of 24 students.

The Questionnaire

It is widely accepted that students' difficulties or beliefs about physical phenomena can be thoroughly investigated using well-designed tasks, aiming at distinguishing the factors affecting their cognitive difficulties. In this way, we can reveal students' mental models and diagnose the main sources of their alternative conceptions. The tasks we developed, for the purpose of this study, were representing everyday examples of real objects' motion. We chose the area of sport games, which is considered familiar and attractive for the great majority of the students in Greece.

Our research tool was a three-task questionnaire, based on open-ended questions (see Appendix). The structure and the design of multiple-choice responses were based on students' alternative conceptions or ideas recorded during the trial phase. Most of them have also been reported in the literature (Clement, 1982; Enderstein & Spango, 1996; Halloun & Hestenes, 1985; Palmer, 1997; Watts & Zylbersztajn, 1981).

Students were asked to present their beliefs about the physical situations described in the various tasks by selecting their responses between the correct answer and a series of implicit alternative conceptions. The key elements in their alternative beliefs were:

1. Consideration of the force originally exerted on the body on the axis of motion;
2. Ignoring the gravitational force;
3. Perception that the forces of action and reaction are both exerted on the body during its motion;
4. Combinations of the above ideas.

It has been reported that the use of multiple-choice questions can give misleading results and also that they overestimate students' knowledge (Palmer, 1997; Tamir, 1990). Indeed, in many cases, multiple-choice questionnaires could help students to choose the correct answer for reasons not scientifically valid. This type of questions often demands students to analyse the relative value of the various choices, if they believe that more than one answer is correct. To overcome the reasons above we asked students to justify their responses thoroughly by describing the forces exerted and also explaining their cause. This way we have identified two more approaches, not explicitly included in our questionnaire, corresponding to

- correct answers with inefficient justifications (in tasks 1, 2);
- no answer at all (in task 3).

The Statistical Method

Multivariate analysis methods have evolved considerably last decade, and their applications have expanded in various disciplines (Benzécri, 1992; Gifi, 1990) including educational research studies (Marcoulides & Herhberger, 1997; Tacq, 1997). They constitute tools suitable to investigate relationships between variables, especially when research data concern simultaneous measurements of many parameters (Jonson & Wichern, 1998). Analytically, multivariate analysis methods incorporate possibilities like:

1) *Data reduction*, to the degree that the situation under study can be represented as simply as possible.
2) *Sorting and grouping variables*, in order to investigate similarities and dissimilarities between groups.
3) *Investigation of the dependence and/or interdependence relations among variables*.
4) *Prediction of relationships between variables*.
5) *Statistical hypotheses posing and testing*, in terms of the various parameters of the multivariate population (sample).

There are many methods of multivariate analysis, which primarily differ in the data sorting techniques used. *Multiple Correspondence Analysis (MCA)* is a well-established multivariate method allowing us to analyse and describe graphically and synthetically a large amount of research data (Benzécri, 1992; Lebart, Morineau, & Pitron, 1998; Micheloud, 1997). It offers effective tools that can help us to overcome the intrinsic limitations of the descriptive statistics. This method is also known as Homogeneity Analysis (Gifi, 1990; SPSS, 2002) and Dual Scaling (Nishisato, 1980). It aims at the graphical representation of the structure of non-numerical multivariate data. The central principle of the MCA method is that complex multivariate data can be accessible by displaying its main regularities and patterns in graphs and diagrams.

The subjects under study are usually described by a large number of parameters. The fine structure of students' alternative conceptions and mental models cannot be revealed through conventional statistical methods. With the help of the MCA method we are able to derive not only students' alternative conceptions but also how their ideas correlate across the various tasks. Furthermore, we can construct a topographic map of those parameters, thus making students' classification easily presentable on the basis of their cognitive approach to the different tasks (Jimoyiannis & Komis, 2001). To our knowledge this study is one of the first applications of the MCA method in interpreting research data concerning students' ideas about physics concepts and phenomena.

Although the subjects have been randomly selected from six typical public high schools, the intrinsic characteristics of MCA do not allow us to generalise our results and to attribute valid rules about the population which the research subjects are coming from. It should be noted at this point that MCA is an exploratory technique, which deals mainly with the structure of the subjects under study.

The method of MCA was developed based on the principle that emphasises the development of models that fit the data, rather than the rejection of hypotheses based on the lack of fit (Benzécri, 1992; Greenacre, 1984). Contrary to conventional inferential statistical methods, in MCA there are no technical assumptions posed (Lebart, Morineau, & Pitron, 1998). For this reason MCA can be applied to data analysis without the necessity to check any assumption about the forms of the relevant data. The detailed correlation between the values of the numerous variables that characterise the subjects has a qualitative form allowing us to construct valid assumptions offered for further study and analysis.

Descriptive Analysis

Our analysis is not restricted to the various types of answers chosen by the students in the sample. It aims at investigating the relationships between students' responses and the reasoning patterns used.

At the first level, our analysis has identified a set of beliefs and ideas corresponding to the students' responses recorded in the individual tasks. The related procedures are classified in categories according to the reasoning key element used. Table 1 classifies the frequencies of each type of reasoning, in the three tasks of the questionnaire.

The identified reasoning types are analysed as follows:

Correct Answer with Correct Justification (C)

Students following the above procedure provided scientifically correct justifications, like:

There is the gravitational force only exerted to the ball during its motion

The force originally exerted acts instantaneously. The ball is moving under the sole influence of gravity when it leaves player's hand (after player's kicking with his racquet or bat)

Since there is no wind resistance (or friction), the ball's movement is influenced only by the gravitational force.

Correct Answer with Insufficient Justification (CU)

Students grouped in this category selected the correct answer (tasks 1, 2) but they gave insufficient explanations or no justification at all. Most of them exhibited the following arguments:

There is the gravitational force only, because the force originally exerted to the ball by the player (racquet or bat) is slowly weakening and, finally, becomes zero at the upper point

Table 1
Types of Students' Reasoning Procedures.

Procedure type	Task 1		Task 2		Task 3	
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
C	42	28.8	52	35.6	24	16.4
CU	9	6.2	9	6.2		
FB	91	62.3	60	41.1	90	61.7
NF	4	2.7	17	11.6		
F			8	5.5	12	8.2
ARB					13	8.9
AR					5	3.4
NA					2	1.4
Total	146	100	146	100	146	100

C: Correct answer with correct justification; CU: Correct answer with insufficient justification; FB: The original force is continuously exerted in the direction of motion; F: There is only the original force exerted in the direction of motion; NF: There is no force at all; ARB: Action, reaction and the gravitational force; AR: Action and reaction forces; NA: No answer.

The ball is moving upwards because the force originally exerted by the player is greater that the gravitational force. Since it is slowly weakening and becomes zero at the upper point, the ball starts its downward motion.

It is evident that the students above implicitly consider that the original force is still exerted on the ball, during its motion.

The Original Force is Continuously Exerted in the Direction of Motion (FB)

The great majority of the students in the sample believed that the force due to the initial impulse is continuously exerted on the ball during its movement. Characteristic justifications given were of the type:

There are the originally exerted force to the ball by the player (racquet or bat) in the direction of motion and the gravitational force.

There is only the Original Force Exerted in the Direction of Motion (F)

Students grouped in this category believed that only the original force is exerted on the ball during its movement. Those students totally ignored the gravitational force, arguing that

There is only the force exerted by the player (racquet or bat) in the direction of motion.

There is no Force at all Exerted on the Ball (NF)

Students grouped in this category concentrated their reasoning on the kinematical elements regarding the upper position of the ball's movement (tasks 1, 2). They believed that there is no force exerted on the ball at the upper point. They presented explanations like:

There is no force exerted on the ball, because its velocity at the upper point of its flight is zero.

There is no force exerted on the ball, because it stops its upward movement.

The concepts of velocity and acceleration at the upper point of a vertically thrown object are described as a topic of special difficulty (Arons, 1981, 1990). It has also been recorded, in a previous research administered in Greek schools (Jimoyiannis, Mikropoulos, & Ravanis, 2000), that the upper position of a vertically upwards thrown object constitutes a difficult situation for the majority of the students. It seems that the above difficulties are not restricted to the kinematical concepts only, but strongly affect students' ideas about the forces involved in this situation.

Action, Reaction and the Gravitational Force (ARB)

In the third task, 13 students exhibited the idea that the action-reaction forces, due to players' (racquet's or bat's) kicking, are both exerted on the ball. They also thought that the above forces act continuously during the flight of the ball (task 3):

The forces exerted are: a) the gravitational force, b) the force exerted to the ball by the player (racquet or bat) and c) the force exerted to the player (racquet or bat) by the ball.

There are two oppose forces (action-reaction) and the gravitational force.

There are only the Action and Reaction Forces (AR)

There is also another group consisted of five students which considered that the action-reaction forces are both exerted to the ball during its flight (task 3). Furthermore, they ignored the existence of the gravitational force in their reasoning. Justifications of this type are like:

There are only the action and reaction forces exerted to the ball.

There are only the action and reaction forces. The gravitational force does not act because the ball is in the air.

No Answer (NA)

Only two students followed this approach giving no response to task 3.

Multiple Correspondence Analysis

Multiple Correspondence Analysis provides us with a wider perspective concerning students' representations and their classification in conjunction with relevant parameters, such as their age, gender, school attended and other characteristics (Benzécri, 1992; Greenacre, 1993). We have chosen this type of analysis because it can help us to reveal the various correlations and to study students' knowledge and alternative conceptions thoroughly (Jimoyiannis & Komis, 2001). In particular, the employment of this analysis aims to:

1. Identify students' mental models and alternative conceptions;
2. Understand the structure and the organisation of students' knowledge;
3. Reveal how students' beliefs and mental models are grouped or correlated.

We employed our analysis using the software SPAD version 5 (SPAD, 2000). We applied the CORMU (Correspondences Multiples) method, which is equivalent to the HOMALS (Homogeneity Analysis) procedure of SPSS version 11 (SPSS, 2002). As dependent variables we have used the various responses students gave to the three tasks and students' age, gender and school were used as independent variables.

With MCA we can derive a number of factors, which determine all the information produced. Each factor is described by two parameters (Benzécri, 1992):

- *The eigenvalue* λ, which corresponds to the eigenvectors characterising the values of the variables implicated in the analysis.
- *The coefficient of inertia* τ, which is the proportion of the total information in the factor, as it is provided by the MCA analysis.

The factors produced in MCA and the relevant eigenvalues depend on a) the number of research variables, and b) the number of values of those variables. It should be noted that MCA reveals at the most $m - n$ factors, where n is the number of the variables and m their independent values. In the case of our study, there are 3 variables (corresponding to the research tasks) and 15 values (corresponding to the various students' responses) producing at the most a total of 12 factors.

We can classify MCA factors in descending order according to their importance, as far as the total information provided. Table 2 presents the eigenvalues and the coefficients of inertia for the first five factors revealed by our analysis. As we can see, they cumulatively represent the inertia at a percentage of 64.05%, which corresponds to 64.05% of the total information produced. In our case, we analyse extensively only the first and second factors, which offer 33.37% of the total information and allow us to interpret 13 of the 15 values. For this reason it is not necessary to extend our analysis to the lower order factors, since they can give only complementary information about the same values.

Table 2
MCA Parameters' Values.

Factor	Eigenvalue	Coefficient of inertia	Cumulative percentage
1	0.6498	17.72	17.72
2	0.5737	15.65	33.37
3	0.4371	11.92	45.29
4	0.3550	9.68	54.97
5	0.3332	9.09	64.05

The first axis (factor) has *eigenvalue* $\lambda_1 = 0.6498$ and *coefficient of inertia* $\tau_1 = 17.72\%$. This is characterised as the *well-structured conceptions – alternative conceptions axis*. It is a very important factor in our analysis, since it shows the contradiction between:

1. the students' correct responses with effectual reasoning, and
2. the alternative conceptions exhibited by most students in the sample, which were based on the idea that the original force is continuously exerted to the ball during its movement.

It is evident that students' answers are explicitly grouped around two poles. The first pole is defined by the students having well-structured mental models about the relation between motion and force (C reasoning procedures, according to the coding of Table 1). The second pole is determined by those students, which believed that the forces exerted on the ball, during its motion, are the initial impulse and the gravitational force (FB). There also belong those students who exhibited a similar reasoning procedure (CU) in tasks 1 and 2 arguing that

The force originally exerted to the ball by the player is slowly weakening and becomes zero at the upper point.

The second axis (factor), with *eigenvalue* $\lambda_2 = 0.5737$ and *coefficient of inertia* $\tau_2 = 15.65\%$ is characterised as the *well-structured conceptions – various misconceptions axis*. This axis opposes students giving correct responses (C) with their fellows, which basically ignored the gravitational force in their reasoning. Those students mainly concentrated their procedures on ideas where the forces exerted on the ball during its motion are: the original impulse only (F); the action and reaction forces (AR); the action-reaction forces and the gravitational force (ARB); no force at all (NF).

Figure 1 shows the graphical representation of our results in the plane created by the first two axes. Students' responses are represented in the graph in the form of a task number-reasoning procedure code. The values of the variables, when projected on the factor plane define three clouds:

1. The first cloud N1 is defined by the values that correspond to *well-structured conceptions* (values T1C, T2C, T3C). Task 3 has been responded to correctly by a small number of students, since the corresponding values are projected far from the origin of the two axes. The value concerning Lyceum 8 is found inside cloud N1. This means that students in Lyceum 8 have exhibited, at a larger percentage, scientifically correct answers to the various tasks. In this case, it seems that students' engagement with experimental tasks in the physics laboratory helps them to construct scientifically correct mental representations about motion and force. In conclusion, cloud N1 represents a group of students who have built scientifically consistent representations about the force-motion relation.
2. Cloud N2 is determined by the values corresponding to the *alternative conceptions* based on the belief that *the original force is continuously exerted to the ball during its motion* (values T1FB, T2FB, T3FB, T1CU, T2CU). As shown in Figure 1, there is a group of students who persistently exhibited the above alternative conception in all the three tasks of the research.
3. Cloud N3 gathers *various misconceptions*. There are located ineffectual responses where the key element in students' reasoning is that they *ignored the gravitational force* (values T3F, T2NF). There are also placed inside cloud N3, the students who believe that the *action-reaction* forces are both exerted to the ball during its motion (values T3AR, T3ARB). As we can see, there is a strong correlation between the values of clouds N2 and N3, a situation referred in the literature as the *Gouttman effect* (Lebart, Morineau, & Pitron, 1998). This indicates that the students described by those values vacillate in the various tasks between two types of alternative conceptions: considering the original force and ignoring the gravitational force. The above correlation is also indicated by the presence of the value T2F (corresponds to students who recognise only the initial force and ignore the gravitational force) near cloud N2.

We can derive, considering the position of the independent variable values in the factorial graph (Figure 1), that the medium age students (16 years old), the boys and the students coming from Lyceum 1 are generally classified, near cloud N1 of the efficient answers. On the other hand, the younger students (15 years old) and the older ones (17 years old), the girls, and those coming from Lyceums 2, 4, 7 and 9 are found near the clouds of the inefficient answers.

Summary and Conclusions

From a qualitative point of view, we have identified common students' alternative conceptions about force and motion found in related surveys (Enderstein & Spango, 1996; McCloskey, Caramazza, & Green, 1980; Watts & Zylbersztajn, 1981). Furthermore, our analysis derived three discernible groups of students with a persistent and rather consistent approach to the various tasks:

1. An extended group of students having the belief that "the original force is continuously exerted on the ball during its motion."
2. A second group of students which, generally, responded correctly to all the three tasks.

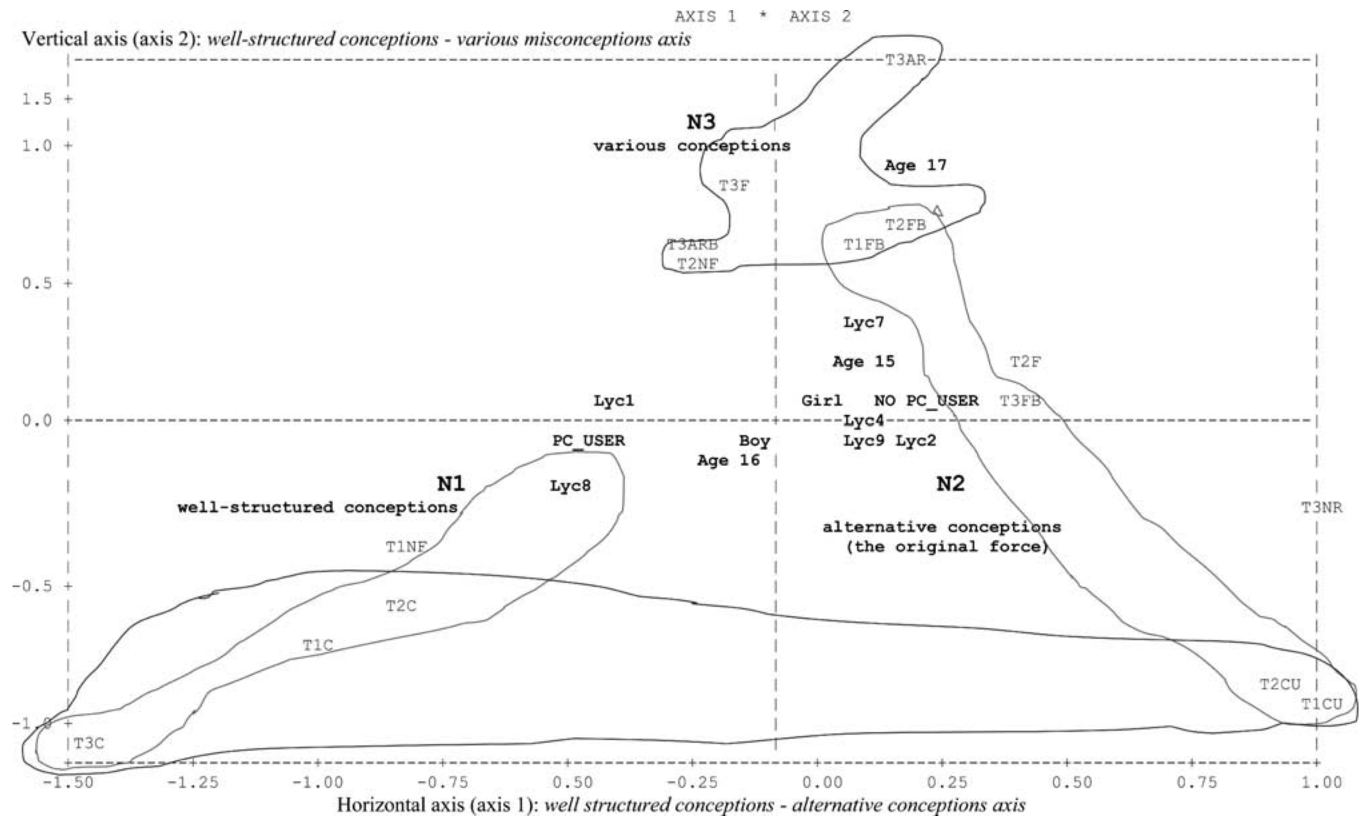

Figure 1: Graphical representation of students' ideas about forces and motion. The factorial plane is defined by the first two factors. Explanation of symbols in text in *Multiple Correspondence Analysis* section.

3. A third group of students, who ignored the presence of the gravitational force and/or believed that the action-reaction forces were also exerted on the moving ball.

The majority of the students in this study held the alternative conception that "there is need for a force in the direction of motion to sustain motion" at a proportion of 68.5% in the first, 52.8% in the second and 69.9% in the third task. It is also derived by our analysis that most of the students in the sample used consistent reasoning procedures that involved a motion force. In other words, they exhibited this belief in all the tasks of the questionnaire.

Our results show better students' performance when compared with those reported in previous studies, which have found percentages between 80–93% (McCloskey, Caramazza, & Green, 1980), 85% (Watts & Zylbersztajn, 1981), and 78–94% (Enderstein & Spango, 1996). However, our results do not confirm the findings of Enderstein and Spango (1996) concerning the percentage of students who ignored the presence of gravitational force. We have recorded a significantly lower percentage of students who held the above idea, ranging between 2.7% (task 1), 17.1% (task 2), and 11.6% (task 3). The alternative conception, that the action-reaction forces are both exerted on the ball during its motion (task 3), is dominant in students' reasoning at 12.3%. This idea intervenes in students' beliefs about the motion force and restricts their ability to effectually apply Newton's laws in everyday life situations.

Furthermore, it seems that the contextual features of the situation presented (the type of motion, the position of the ball, its implied velocity, etc.) determined, at a large part, students' ideas about the motion force and the presence of the gravitational force. This confirms the findings reported by Palmer (1997) about the role of contextual parameters in students' reasoning about motion and forces involved.

In task 2 we have recorded higher scores in students' responses. The physical situation described in this task constitutes a common subject in Lyceum's physics classes in Greece. Furthermore, a similar exercise is also included in the physics textbook (Vlachos, Grammatikakis, Karapanagiotis, Kokkotas, Peristeropoulos, & Timotheou, 1999). Since the great majority of the students in the sample exhibited a shallow understanding of Newton's Third Law, it seems that most of them applied rather mechanically their knowledge in the above situation. This is also supported by the total lack of the misconception concerning the action-reaction forces in the physical situation of task 2.

The main implications of our investigation are:

1. It seems that their alternative conceptions have served students well in providing satisfactory interpretations or predictions of motions in the world around. Students' beliefs are contrary to the Newtonian theory and to the school knowledge too. They originated from and are strongly supported by their everyday experience of real life phenomena, where friction impedes motion. Because of friction, we have continuously to act a force on the axis of motion, in order to keep an object moving. Since the majority of students are not able to immediately attribute this to friction, their alternative conception "a force is required to sustain a motion" remains unchanged even after a series of lessons concerning Newton's laws.

2. 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. Traditional instruction methods are ineffective in fostering students' conceptual change (Glaserfeld, 1992; Vosniadou, 1994). Physics courses and instructional activities should be revised in the framework of a qualitative approach of the various concepts, in order to promote students' active engagement. Properly designed experimental tasks in the Physics laboratory should offer cognitive conflict situations that will effect conceptual change, as students try to resolve them (Shaffer & McDermott, 1992; Tao & Gunstone, 1999). Our results, concerning the performance of the students of the 8th Lyceum of Ioannina are consistent with the argument above.
3. 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." Schematic modeling instruction proposed by Halloun is an effective approach in promoting this evolution (Halloun, 1998, 2000). In such a process, students develop all tools and habits needed for scientific inquiry in four-stage learning cycles (exploration, invention, formulation, exploitation).
4. Computer simulations and modeling educational software can also be effective tools, easily applied in the schools, in order to support modeling instruction (Jimoyiannis & Komis, 2001; Tao & Gunstone, 1999). They constitute open environments that provide students with the opportunity:
   - to develop their meaningful understanding about physical concepts and phenomena, through an active process of making hypotheses and testing ideas,
   - to employ a variety of representations and express their own ideas about physical phenomena,
   - to investigate friction-free situations which are difficult to experience in the physics laboratory.
5. Finally, a rigorous effort should be directed to in-service teachers' training courses, dealing with the adaptation of new approaches concerning physics instruction in Greek secondary education schools.

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Notes

1. Lyceums are schools providing upper secondary education in Greece (3 grades in total).

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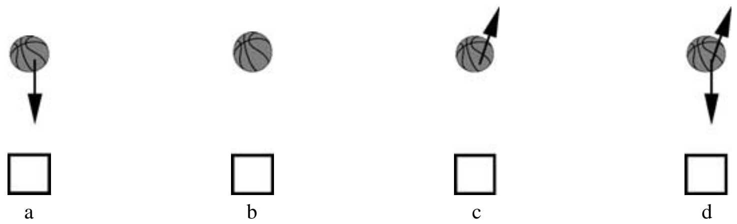
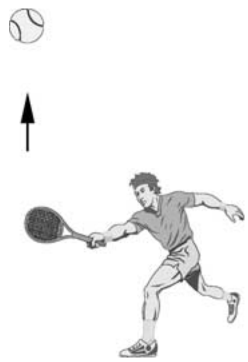
Appendix. The questionnaire

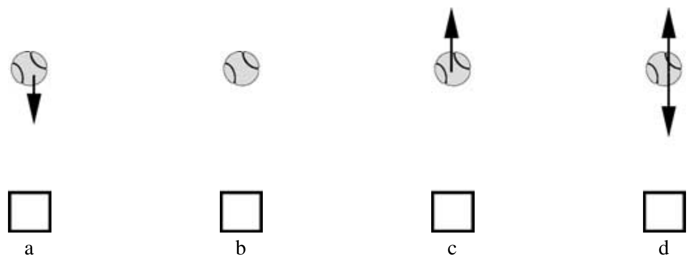
Read carefully the questions in the following tasks and check the rectangular with the correct answer. Justify your answers. Consider all situations in the gravitational field of the earth. Ignore the resistance of the wind.

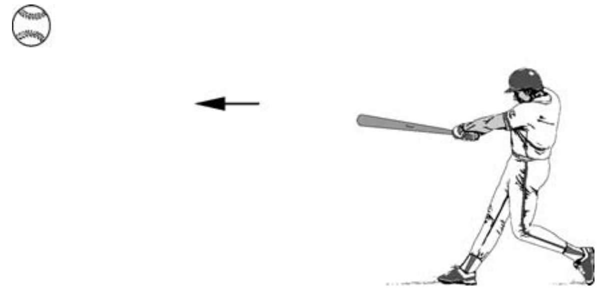
Task 1. A basketball player throws the ball to the basket, as shown in the figure. Which one of the following cases shows correctly the forces exerted on the ball at the uppermost point of its trajectory.





Task 2. A tennis player, handling his racquet badly, hits the ball vertically upwards, as shown in the adjacent figure. Which one of the following cases shows correctly the forces exerted on the ball at the uppermost point of its trajectory.





Task 3. A baseball player hits with his bat the ball horizontally, as shown in the adjacent figure. Which one of the following cases shows correctly the forces exerted on the ball during its motion.