ALTERNATIVE IDEAS IN MECHANICS: WHERE CAN THEY COME FROM?

Manuel Sequeira and Laurinda Leite
Universidade do Minho - Instituto de Educação
4700 BRAGA - Portugal

INTRODUCTION

Since the late seventies there has been an ever increasing interest for the study of alternative ideas in science topics. Mechanics soon deserved researchers' special attention and is surely the topic on which the largest number of studies has been carried out. Almost all these studies concentrated on the identification of students' alternative ideas, leading to the conclusion that they do exist and resist to instruction.

Although Viennot, in 1979, had already pointed out that the set of spontaneous, intuitive or natural explanations held by students about mechanics "could not only be the result of ignorance or deformation of formal knowledge" (Viennot, 1979), very little progress has been made towards the identification of the causes of students' alternative ideas in mechanics. However, a few authors have tried to find an answer to the questions: a) Why do people construct some personal concepts? and b) Why do those concepts differ from and resist to what people are taught?

According to P. Hewson (1985), people' ideas or concepts exist as a result of a process of natural selection undertaken by the individuals' intelectual environment which favours the development of some concepts and inhibits the development of others. The individuals' construction of ideas and concepts about the natural world requires a fit between the subjective purpose of knowing and the objective context. When doing so, individuals often look at something as if it were something else, seeking for analogies which help them to achieve that fit (Guidoni,1985). The natural analogical reasoning undertaken in this process is based on individuals' schematic prototypes or duplicating schemes which often lack in fit and/or are handled by strategies not enough developed. In any of these cases, natural analogical reasoning is likely to lead to natural thinking and alternative ideas. The existence of similar basic ideas in different individuals is due to the fact that their way of processing ideas is driven by the invariance of external phenomena and by stable cultural patterns. Therefore, M. Hewson (1985) calls our attention to the fact that the origin of alternative ideas has to be viewed in the context of people's intellectual environment. According to P. Hewson (1985), it includes individual and social beliefs, language, accepted theories, observed facts and events. It has also been argued that actions on the world, social interaction (Ogborn, 1985), learners' previous mental schemes (Driver, 1988), differences between accepted ideas and ideas presented by some teachers and textbooks, teachers' unwareness of students' alternative ideas and the way science content is sequenced, organized and "presented" to the students (Martins, 1989) can also contribute to alternative ideas.

Despite the fact that multiple sources of alternative ideas have been pointed out in the literature, the work done on this topic consists mainly of theoretical reflections based on the results of studies aiming to identify students' explanations about mechanics phenomena.

This paper aims to be the authors' first attempt to identify some causes of secondary school students' alternative ideas in mechanics. The research reported here shows the first results obtained within a larger project focusing on the origin of students' ideas in mechanics.

METHODOLOGY

Taking into account the diversity of origins of alternative ideas referred to in the literature and in order to get as much information as possible, data were collected from three sources: students, physics teachers and textbooks.

To investigate where students get their alternative ideas from, eight secondary school students (four nineth graders, who had not studied mechanics, and four tenth graders, who had studied this topic for the first time) were interviewed by one of the authors, about four problematic situations (Appendix 1). These situations can be interpreted by the use of mechanics, although they are often explained by students based on their own ideas (Sequeira and Leite 1989; Sequeira, Leite and Duarte, 1989). The sequence of the interview is basically the following: describe what happens; explain why; how do you know that / where did you get that idea from.

To investigate whether physics teachers hold alternative ideas on mechanics, a questionnaire was prepared by the authors and responded by 17 teachers. This questionnaire contains the four problems referred to above and some possible answers to each question of the problems, including the correct answer and the most frequent alternative answers among students, before and after instruction on 10th grade mechanics. Teachers were asked to circle the correct answer to each question.

Finally, a brief analysis of the chapter of mechanics in the four most important Portuguese 10th grade physics textbooks was carried out in order to evaluate the extent to which textbook writers take students' ideas into account and promote their conceptual change.

DISCUSSION OF RESULTS

The data collected from the different sources considered in this study will be analised separately: students, teachers and textbooks.

A - Students

The alternative ideas expressed by the interviewees participating in this study are similar to the ideas identified by the authors in some previous studies (e.g. Sequeira and Leite, 1989; Sequeira, Leite and Duarte, 1989).The number of interviews is very low and therefore no statistics will be performed. Rather, interviewees' answers will be used in a descriptive way in order to get some insight on possible causes of students' alternative ideas.

The main alternative ideas expressed by the students can be summarized as follows:

> 'Objects need a support, whatever it is, otherwise they cannot stand and they fall. The falling velocity of the objects depends on their weight so that the heavier object falls faster, when fall occurs in the air. In the vacuum, objects do not fall because there is either no atmosphere or no gravity. When objects are moving, there has to be a force or a net force acting in the direction of motion. If, at a given instant, this force stops and another force is applied to the moving object, the direction of motion changes to the direction of the applied force. The force (or the net force) acting on a moving object is proportional to its velocity. If the force stops, the object either stops immediatly or continues moving for a while with slowing down motion or it falls.'

Let us now try to identify the possible causes for the alternative ideas expressed by the students.

1 - *Objects need a support, otherwise they would fall.*

Students are used to see objects either on a support (such as a string, the ground, another object, etc.) or falling (when the support is taken away). Therefore, they cannot accept the idea of a spaceship moving in deep space without a support which can be either an engine on or an upwards force. This can be illustrated by the following quotations taken from the interviews.

> "... If the spaceship has no force it falls; There has to be something holding it up. I am sure... There has to be an upwards force to keep the spaceship up there... It needs the engine N on [to move from left to right] and... an upwards force to keep it up." (10th grader);

> "[When the only engine on is turned off, the spaceship] falls... the spaceship cannot stand... it cannot stay there. When a person feels weak he/she faints because he/she is not strong enough to stand up The spaceship would stop only after falling." (10th grader).

2 - *The heavier an object is the faster it falls, in the air.*

The interviewees were asked to compare the falling time of two equal size spheres, one made out of iron and the other made out of wood, when they are released from the same level, in the air. They all stated that the "iron sphere would fall faster because it is heavier than the wood sphere". They argued they knew it from their everyday experience with "heavy" and "light" objects and even described some experiences which they had done or could do in order to corroborate their previous answer. Some examples of experiences described by the students are given below.

> "[I have done an experiment] with stones... a bigger stone and a smaller stone; the bigger stone falled faster than the smaller stone." [9th grader];

> "I have done [an experiment] with a piece of chalk and a stone... the stone reached the ground sooner because it is heavier." (10th grader).

The air resistance is always there and students do not perceive its influence on the falling time. They only perceive the influence of what may or may not be there and therefore base they answers on it. Weight is a characteristic of the objects which students easily perceive as changing from one object to the other and that seems very appealing to them.

3 - *In vacuum, objects do not fall; they float.*

Students have watched TV programs and science fiction films in which they could see astronauts floating either in the moon or in deep space. They know that in the moon, like in outer space, there is no atmosphere. They, therefore, deduced (incorrectly) that the non existence of atmosphere was the cause of floating in space and answered to the question about the spheres in the vacuum tube based on the characteristic it has in common with outer space, that is, absence of atmosphere. An illustrative example is given below.

> "... As there is no air, they would stay in the same place; they would not fall... In outer space there is no air and people float [I have watched it] on TV." (9th grader).

On the other hand, some students know that the weight of an object is smaller on the moon than it is on earth. Besides, they can watch on TV, people floating on the moon's surface. Then, they conclude that in vacuum there is no weight/gravity and, therefore, they state that objects do not fall inside a vacuum tube.

4 - *Motion requires a force in the same direction.*

Students live in a world with friction where they have to exert a force on any object they want to keep moving in a well defined direction or with a certain velocity. Therefore, they invent forces to explain slowing down motion consistently with their everyday experience that motion requires a force in the same direction. One student put it this way:

> "... the coin goes up... due to the fact that the force I gave to it is bigger than... the force of gravity; otherwise, the coin would not go up" (10th grader).

This belief is so deeply rooted in students' minds that, even after studying Newton's first law, students hardly accept objects moving in a frictionless space, without any applied force. This statement can be illustrated by the following quotation from students' interviews:

> "The spaceship would not move if there was no engine on. The engine N is on... because it is behind the spaceship... It exerts a force on the spaceship so that it can move." (10th grader).

> "Engine N is on... there has to be something that makes spaceship move like that." (10th grader).

As it had already been found in a previous study (Sequeira and Leite, 1989a), sudents feel a need for a cause to explain every phenomena. Maybe, because of that, they hardly use the law of inertia which does not include any causal relationship.

5 - *Force is proportional to velocity.*

Almost all interviewees stated that the speed of the spaceship moving in deep space (no friction, no gravity) would be constant if the functioning power of the engine is constant, it would increase with the the power of the engine and would decrease with it. Some students stated that they knew it from their

> "... experience with cars... If we accelerate more and more, the car goes faster and faster; if we accelerate less and less, it goes slower and slower; [if acceleration is constant, the speed] will be constant" (10th grader).

6 - *The direction of motion changes to the direction of the applied force.*

Some students stated that the spaceship moving horizontally (they say, with engine N on) would change instantaneously to the vertical, when engine N is switched off and engine K is switched on. These students do not consider the inicial velocity of the spaceship and base their answers only on the position of engine K.

However, other students acknowledge the idea that the direction of motion does not change instantaneously to the direction of the applied force/engine on. These students base their answers on their everyday experience with cars changing their direction of movement, as illustrated below.

> "[The spaceship]... would change its trajectory... and it would go down... I am... comparing it... with a car. The car does not move immediatly from one direction to the other." (10th grader).

But these students believe the change of direction would occur very rapidly so that, after a short while, the spaceship would be moving in "the direction of the engine on".

7 - *If the force stops, the objects either stop immediatly or continue moving for a while, with slowing down motion, or they fall.*

When the force acting on a moving object stops (engine turned off or force used up), the object stops immediatly "because there is no longer a force acting in the direction of motion". Other students believe the object would fall due to the non-existence of a "support".

However, some students accept the idea that the spaceship can move after the engine is turned off but they refuse the idea that it continues moving with the same velocity after the engine is turned off. They put it as follows:

> "The spaceship loses the force but it continues moving downwards... At first, it moves faster but after a while it moves slower.[At the biginning] it still has the force the engine has given to it. [Later] the force will vanish."(10th grader].

This kind of explanation seems to be based on students' experience with cars, as explained by one of the interviewees:

> "It is not because one switches off the engine of a car that it does not move... The spaceship would continue moving downwards... until it reaches the ground.When this happens, it stops... As the spaceship gets nearer the ground, its velocity would decrease" (10th grader).

B - *Teachers*

When physics teachers responded to the questionnaire with the same problems of the interview conducted with the students, some of them gave alternative answers, as shown in table 1.

TABLE 1 - Physics teachers' performance by problem.

(N = 17)

Problem	Correct answer		Alternative answer		Cannnot answer	
	f	%	f	%	f	%
Spaceship	14	82	2	12	1	6
Coin toss	11	65	5	29	1	6
Two spheres:						
- air	6	35	11	65	0	0
- vacuum	17	100	0	0	0	0
Book on table	17	100	0	0	0	0

Teachers' alternative answers include the following ideas: a) the heaviest of two equal size spheres falls faster, in the air, because it is the heaviest (Two spheres problem); b) when a coin is tossed up, it acquires a decreasing upwards force (Coin toss problem); c) the spaceship moving in deep space with constant velocity requires an engine on or a net action of several engines in the direction of motion (spaceship problem); d) The direction of a moving object changes abruptly to a different and permanent direction, when a force is applied to the object (Spaceship problem).

In a previous study, 16 physics teachers were asked to answer to a different version of the spaceship and the coin toss problems, under examination conditions. Only 25% of the teachers were able to answer correctly to the spaceship problem and 50% to the coin toss problem. The remaining teachers expressed alternative ideas similar to those usually expressed by students (Sequeira and Leite, 1989).

The results presented here corroborate the statement that some alternative ideas are very resistent to science teaching and lead us to question ourselves about the effectiveness of physics teaching. We cannot say, in the context of this study, that teachers who hold alternative ideas would present them to their students. If they were going to use this problems in their classes they would hopefully think about them and teach them according to newtonian mechanics. However, teachers can be faced with students' alternative ideas which are similar to the ideas they themselves hold unconsciously. In this case, we think that it would be very difficult for the teachers to perceive that the ideas held by their students need to be changed and therefore they would not promote students' conceptual change. Another possibility would be that students undergo a conceptual change of their own ideas to the teachers' alternative ideas.

C - *Textbooks*

A brief analysis of the chapter of mechanics in four 10th grade physics textbooks (Silva and Valadares, 1985; Almeida and Silva, 1984; Sá, 1987; Pereira et all, 1983), leads us to conclude that textbook writers do not take into account students' alternative ideas about mechanics concepts and principles. Athough several cognitive science studies have shown that very few concepts (if any) included in 10th grade mechanics are really new to the students, the textbook authors state objectives for the students to master concepts and principles as if they were all new to 10th graders entering mechanics classes. It seems that the authors of the textbooks are more concerned with the amount of "new" concepts the students are supposed to learn (probably, by rote learning) than with the conceptual change of the students' prior ideas into meaningful accepted concepts.

The contents included in mechanics are basically the same (following the syllabus) and in general there is little integration, if some, among the different contents, namelly between kinematics and dynamics. Silva and Valadares (1985) try to develop some concepts further than the other authors do and present them in a slightly different sequence which seems more promising in terms of giving students a better understanding of some concepts. Two of the textbooks (Sá, 1987; Almeida and Silva, 1984) introduce too many concepts to describe motion, being some of them unnecessary and even confusing to students. In fact, they use, for example, the concepts of average velocity and average acceleration as being scalar quantities, related to the change of position measured over the trajectory, instead of the accepted concepts of average velocity and average acceleration as vectorial quantities, related to the change of position in a given frame of reference. The accepted concepts of average velocity and average acceleration are labeled by these textbook authors as vector average velocity and vector average acceleration. It should be noticed that, in these textbooks, the words average velocity and average acceleration do not mean the magnitude of the vector average velocity and the vector average acceleration. We are affraid of the possibility of sudents not perceiving these differences of meanings and getting even more alternative ideas than they already have.

In what concerns the presentation of the content, none of the textbooks takes into account the existence of certain alternative ideas among students even when they have a good opportunity to do so without any extra effort. Take, for example, the case of a textbook (Pereira et all, 1983) which describes and suggests students to perform an experiment which would enable them to establish a relationship between the force acting upon a body and the rate of change of velocity. Instead of testing the idea commonly accepted among students that $\vec{F}$ is proportional to $\vec{v}$, the authors assume, from the very beginning, that $\vec{F}$ is proportional to $\Delta\vec{v}$. This procedure does not promote students' conceptual conflict and diminishes the interest of the experiment, as the relationship is to be confirmed and not "discovered".

It is very stricking to find in the textbooks some statements (sometimes in bold) and concept definitions which either are scientifically incorrect or can lead students to reinforce their own ideas. The following paragraphs, which can be found in one of the textbooks, corroborate the previous statement.

> "If there is no force acting on a body, its velocity remains constant; therefore, the body moves on a straight line with uniform motion.
> In summary, we state the first principle of dynamics, that is, the inertia principle, as follows:
> To a nule force it corresponds a nule acceleration. " (Almeida and Silva, 1984, p.100).

In fact, there can be forces acting on a body and its velocity can remain constant. The condition is that the forces are balanced.

Another textbook stated:

> "The weight of a body is, then, the force responsible for the acceleration in free fall, g, that we can observe." (Sá, 1987, p. 141).

The first part of this statement is what students (and even some physics teachers) say and deeply believe in. We believe that one should be very careful when explaining free fall and fully interpret it both in terms of forces (including air resistance) and changes of velocity.

One more example concerns the definition of weight given in one of the textbooks. It is as follows:

> "Weight is the net force of of the forces exerted by the earth upon the bodies" (Almeida and Silva,1984, p.104).

Although the authors of this definition recognize (in a footnote) that it is an approximate definition of weight, we think that there is a need to distinguish between weight and gravity. We believe that we could give students a more accurate definition of weight, as Silva and Valadares (1985) do without making the concept more difficult for them to understand. In fact, it seems that weight as the net force applied to an object, when it is on a support, is not only more correct but, at the same time, more in agreement with their experience. Besides, we would like to argue for the need of speaking about interaction between the earth and the object instead of speaking about atraction of the earth. In doing so, we would certainly contribute to decreasing the number of students feeling like the interviewee who stated:

> "It does not make sense to me... Each object has its weight. If it was the earth that atracts the objects, than it should atract all with the same weight." (9th grader).

CONCLUSIONS AND IMPLICATIONS

The results of this study seem to indicate that:

a) Students themselves can construct and/or find ways of reinforcing their alternative ideas about mechanics phenomena. When doing so, they use information from their everyday experience (with cars, falling objects, astronauts, etc.), from the mass media (namely, from TV programs, science fiction films and books) and from their contacts with relatives, peers and teachers. Students' alternative ideas are often a result of a process in which students interpret different facts and phenomena as if they were analogous because they do not perceive the characteristics that distinguish them. This process seems to be also influenced by students' beliefs which sometimes prevent them from acquiring the accepted ideas.

b) Teachers may contribute to the persistence of their students' alternative ideas or even to the construction of new alternative ideas if they themselves hold these ideas without perceiving them. In this case, teachers are not aware of the need to change students' alternative ideas because they themselves believe in the same ideas.

c) The authors of the textbooks in this study do not take students' alternative ideas into account and some textbooks can even contribute to the reinforcement or the construction of alternative ideas.

Therefore, it seems necessary to take into account the analogies used by the students, in order to help them to discover the fundamental characteristics and the order that lie beneath the appearance of physical phenomena, so that effective learning can occur. It seems also necessary to make teachers aware of the problematic of alternative ideas so that they become conscious of the fact that a) they themselves can hold alternative ideas and b) their students' ideas are resistant to science teaching and require teaching strategies specially devised to promote conceptual change. Besides, physics textbooks need to be revised both in what concerns the underlying theory of learning and the way some physics concepts are defined, sequenced and organized. However, deeper research is needed to identify the causes of students' alternative ideas, so that we can acquire the background information needed to devise appropriate teaching strategies to change students' alternative ideas about mechanics concepts.

REFERENCES

Almeida, C. & Silva, M. (1984). *Física - 10º ano de escolaridade*. Porto: Porto Editora.

Driver, R. (1988). Restructuring the science curriculum: Some implications of studies on learning for curriculum development. *In* Sequeira, M., Leite, L. & Freitas, M. (Eds). *Actas do 1º Encontro Sobre Educação em Ciências*. Braga: Universidade do Minho.

Guidoni, P. (1985). On natural thinking. *European Journal of Science Education*, 7(2), 133-140.

Hewson, M. (1985). The role of intellectual environment in the origin of conceptions: A exploratory study. *In* West & Pines (Eds). *Cognitive Structure and Conceptual Change*. Chicago: Academic Press.

Hewson, P. (1985). Epistemological commitements in the learning of science: Examples from dynamics. *European Journal of Science Education*, 7(2), 163-172.

Martins, M. (1989). *A energia nas reacções químicas: Modelos interpretativos usados por alunos do ensino secundário*. PhD thesis, Universidade de Aveiro.

Ogborn, J. (1985). Understanding students' understandings. *European Journal of Science Education*, 7(2), 141-150.

Pereira, M. et all, (1983). *Física - 10º ano*. Lisboa: Edições Nave.

Sá, M., (1987). *10º Ano - Física*. Lisboa: Texto Editora.

Sequeira, M. & Leite, L. (1989a). O raciocínio causal e a mudança conceptual no âmbito da Mecânica. Paper presented to the "2ª Convenção de Psicólogos Portugueses - Conferência Internacional: A Psicologia e os Psicólogos Hoje", Universidade de Lisboa, Lisboa.

Sequeira, M. & Leite, L. (1989). Qualitative versus quantitative physics and the conceptual understanding of Newton's laws. Paper presented to the "14th Conference of the Association for Teacher Education in Europe", University of Kristianstad, (Sweden).

Sequeira, M., Leite, L. & Duarte, M. C. (1989). Concepções alternativas sobre a queda dos graves: Propostas para uma estratégia de ensino. Poster presented to the "III Congreso Internacional sobre la didáctica de las ciencias y de las matemáticas", Universidade de Santiago de Compostela, (Spain). Published in the Proceedings.

Silva, L. & Valadares, J. (1985). *Manual de Física - 10º ano de escolaridade*. Lisboa: Didáctica Editora.

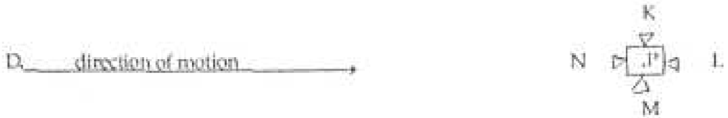
Viennot, L. (1979). *Le raisonnement spontané en dynamique élémentaire*. Paris: Hermann.

APPENDIX 1

THE SPACESHIP PROBLEM

1 - A spaceship with four engines (K, L, M, N) disposed according to picture 1 stands in outer space where there is no friction (no atmosphere) and no gravity.

1.1 - Imagine that the spaceship is moving with constant velocity, and passes by a point D and and after that by a point P (Pict 1).



Pict. 1

1.1.1 - Are any of the engines on when the spaceship moves between points D and P? In case of an afirmative answer, specify which engine(s) is(are)on.

a) In any case, justify your answer.

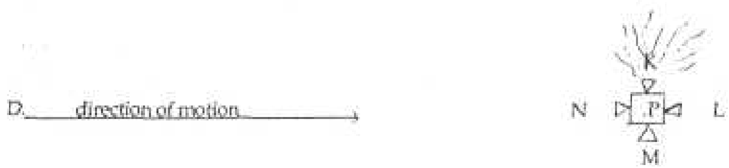
1.1.2 - Is there any force on the spaceship when it passes by point P?

a) Justify your answer.

b) If your answer to question 1.1.2 was "yes", draw, on Pict.1, the force(s) acting on the ship.

1.2 - Immediately after point P engine K is the only engine on, for ten seconds.

1.2.1 - Draw the trajectory taken by the ship during that time. Label the point where the ship will be after the ten seconds by "Q".



Pict. 2

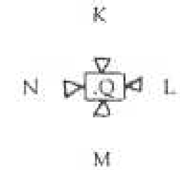
1.2.2 - Describe what happens to the speed of the spaceship between points P and Q.

1.3 - Immediately after point Q engine K is turned off.

1.3.1 - Does the ship stop or does it keep moving?

a) Justify your answer.

1.3.2 - If your answer to question 1.3.1 was "Keeps on moving", *draw on Pict 3 the trajectory you think the ship will take*; If you answered "It stops", you do not need to make any drawing.



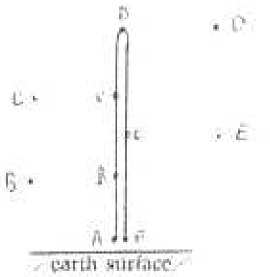
Pict.3

1.4 - In the box below, draw the complete trajectory of the ship and mark points P and Q. *Remember that: The spaceship moves with constant velocity between points D and P;* Between points P and Q engine K is the only engine on; Just after point Q engine K is turned off.

Pict. 4

THE COIN TOSS PROBLEM

1 - Picture 1 shows the trajectory of a coin thrown up vertically into the air, leaving the hand at point A, reaching a maximum point D, falling down vertically, and being caught at point F. Air resistance is to be ignored.



Pict.1

1. 1 - Draw, at the points placed laterally, the force(s) that act on the coin when it is at points B, C, D and E. Label the force(s) represented.

1.2 - Describe the reasoning done to answer to the previous question.

1.3 - Describe what happens to the velocity of the coin:

1.3.1 - during the ascent.

1.3.2 - during the descent.

THE BOOK ON TABLE PROBLEM

1- Picture 1 shows a book at rest on a table.

Pict.1

1.1 - Is(are) there any force(s) acting on the book?

___ No

___ Yes

If you answered "No", justify your answer.

If you answered "Yes", draw the force(s) on Pict.1 and label them.

THE TWO SPHERES PROBLEM

1 - Imagine two massive equal size spheres, one made out of iron and the other made out of wood.

1.1.a - Compare the falling time of the two spheres, when they are released from the same level, in the air.

1.1.b - Describe your reasoning.

1.2.a - What would happen if the two spheres were released from the same level in a vacuum tube (tube without air)?

1.2.b - Describe your reasoning.

SEQUEIRA, Manuel & LEITE, Laurinda (1991). Alternative ideas in Mechanics: Where can they come from? In M. Ahtee; V. Meisalo & H. Saarikko (Eds.), *Proceedings of the International Symposium on the evaluation of Physics Education criteria, methods and implications*. Helsinki: University of Helsinki, pp. 187-201.