Third Misconceptions Seminar Proceedings (1993)

Paper Title: AN ANALYSIS OF THE CONSISTENCY OF SECONDARY SCHOOL STUDENTS' ALTERNATIVE CONCEPTIONS WITH THE COMMON SENSE THEORY OF MOTION

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Keywords: theories,concept formation,,test theory,concept formation,misconceptions,,,
General School Subject: physics
Specific School Subject: mechanics
Students: secondary school

Macintosh File Name: Sequeira - Motion
Release Date: 12-16-1993 C, 11-6-1994 I

Publisher: Misconceptions Trust
Publisher Location: Ithaca, NY
Volume Name: The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics
Publication Year: 1993
Conference Date: August 1-4, 1993
Contact Information (correct as of 12-23-2010):
Web: www.mlrg.org
Email: info@mlrg.org

A Correct Reference Format: Author, Paper Title in The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, Misconceptions Trust: Ithaca, NY (1993).

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AN ANALYSIS OF THE CONSISTENCY OF SECONDARY SCHOOL STUDENTS' ALTERNATIVE CONCEPTIONS WITH THE COMMON SENSE THEORY OF MOTION

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INTRODUCTION

It is already two decades since the time science educators and researchers started concentrating on students' alternative conceptions. Throughout these years they succeeded on both describing students' conceptions on almost all the concepts taught in school science and on identifying their major features (Driver, 1989). Besides, evidence was collected to support the hypothesis that alternative conceptions interfere with the teaching and learning of science, whatever the students' academic ability and the teaching quality of their teachers (Halloun & Hestenes, 1985).

During the last decade several authors have designed and tested some teaching models to change students' conceptions. Some of these authors (e.g. Driver, 1989; Watts & Pope, 1989) seem to believe that conceptual change models may show themselves more efficient in some topics than in others. Consequently, they argue that the efficacy of a teaching model should be evaluated within the context of a given theme.

However, other authors (e.g. Hewson, 1985; Ogborn, 1985; Viennot, 1985; Millar, 1989; Pozo et al, 1991) have argued that unless we know why children think about science concepts the way they do we will hardly be able to promote science teaching and learning. We agree with Mohapatra (1990) on that identifying the alternative conceptions without diagnosing their genesis "is like identifying a desease without diagnosing its cause". Therefore, it seems to us that we need to better understand the origin of students' conceptions before being able to succeed on changing them.

There is a moderate consensus among researchers in what concerns the nature of students' alternative conceptions. In fact, a few authors have argued that they do not exist and that what we call alternative conceptions is just the result of either a strategic inatention (McDermott, 1984) or a conceptualization of the situation based on specific situations previously encountered by the individual (Svensson, 1989). Other authors (Yates et al, 1988) believe that individuals use prototypes to approach new situations. According to them, alternative conceptions would be due to the prototype selected and the relationship between the prototype and the new situation rather than to the application of any law or principle held by the individual.

However, despite noticing some inconsistencies on students' conceptions, several researchers (e.g. Champagne, Klopfer & Anderson, 1980; Maloney, 1980; McCloskey, Caramazza & Green, 1984; Hewson, 1985; Ogborn, 1985; Viennot, 1985; Clough & Driver, 1986) argue that they may belong to some conceptual structures with some degree of generality and organization. These structures are not so organized as those of the scientists' (Guidoni, 1985; Murphy & Medin, 1985) and are based on coherence criteria (Clough & Driver, 1986; Gil-Perez & Carrascosa, 1990) and concepts (Ogborn, 1985; Hills, 1989) different from those in which are based the scientific theories. It may be that the different criteria which explain the coexistence of contradictory microschemas (Champagne, Gunstone & Klopfer, 1983) or it may be that the non-coherence is a characteristic of the learning phase (Shuell, 1990) in which the learner is on the topic under question.

Murphy and Medin (1985) showed how it is possible that an individual may hold a theory which joins together objects which seem to share at first sight very few or even incompatible characteristics. It may be that the difference between the students' and the scientists' conceptual frameworks in what concerns the coherence criteria can explain the difficulty which has been felt in both the identification of possible relationships among students' conceptions and the interpretation of the apparent lack of coherence of the students when they are faced with the task of explaining science phenomena.

Some authors (Pope & Denicolo, 1989) have argued that it is the analysis of these inter-relationships which may reveal the sense and coherence of students' conceptions. Rather than explaining the existence of alternative conceptions, this analysis would lead to the understanding of the content of students' conceptions (Ogborn, 1985). Also, it would help to understand why it might be true that alternative conceptions on mechanics are more resistant to science teaching than on other topics, as Carrascosa and his colleagues (1991) have hypothesized.

Ogborn (1985) has elaborated a model - the common sense theory of motion - which aims to explain the origin of the content of alternative conceptions on dynamics. According to the author, the common sense theory of motion has its origin mainly on the individual's interactions with the real physical world. This world differs from the "newtonian world" in that friction is always present in the former but not in the latter. Although the behavior of the objects can be explained by Newton's laws, the layman does it based on the concepts of effort, support and falling (Ogborn, 1985).

The power of this model to predict students' interpretation of mechanics phenomena was investigated in Britain by Ogborn and his collaborators using interviews (Bliss, Ogborn & Whitelock, 1989) and paper and pencil tests (Whitelock, 1991) based on comics familiar to the students. These studies have shown a fairly high consistency of students' answers with predictions from the common sense theory of motion. This paper aims to analyse the consistency of Portuguese secondary school students' answers to qualitative mechanics problems with the common sense theory of motion.

METHODOLOGY

Population and sample

By the time it was decided to carry out this study the Portuguese Ministry of Education was initiating a curricular reform which included new physical science syllabuses. According to the first proposal for the new syllabuses, mechanics was supposed to be taught to 8th graders, at a qualitative level, and again to 10th graders, at a quantitative level. Therefore, it was decided to work with 8th and 10th graders, studying in Braga secondary schools.

Due to restrictions on the number of participants imposed by the research technique selected (interview) a sample of 15 8th graders and 14 10th graders was drawn from three classes per grade in two secondary schools, on a volunteer base. The criteria used to choose the 10th grade classes was the representativity of the different physics ability classes, as seen by the school physics teachers. No such criterium was used in the case of the 8th grade classes as it was the first year the students were enroled in this academic subject.

Design of the study

We were interested in analysing students' consistency with the common sense theory of motion before they were submitted to any instruction on mechanics and to evaluate the effect of instruction on mechanics. Therefore, we decided to collect data from 8th graders, before any instruction on the topic. This would give us an idea about the initial state of the students when taking mechanics for the first time at the 8th grade (as it was supposed to hapen by the time the study was designed) or at the 9th grade (as it is planned to be in the new syllabus). In what concerns 10th graders, data were collected at the very begining of the academic year (before instruction on 10th grade mechanics and after instruction on the concept of force on the 9th grade) and again two months after the students had finished the study of mechanics

There was no interference of the researchers on the teaching approach followed by each of the three teachers teaching the 10th grade classes to which belonged the students participating in this study. However, an interview conducted separately with the teachers showed that they all followed a similar approach which was heavily baseed on the textbook adopted in the two schools where they were teaching.

Research technique

There is some consensus among science education researchers (Sutton, 1980; Martins, 1989; White & Gunstone, 1992) that every research technique has some advantages and some disadvantages when compared with the others. According to them, the option for a given research technique should depend on the objectives of the study.

Taking into account the shortage of research on the specific topic of this paper and, as far as we know, its non-existence in Portugal, it was decided that the study would be exploratory in character. Therefore, in order to go as deep as possible on students' understandings it was decided to use the interview technique. Furthermore, the interview technique had already been used by Ogborn and his collaborators in some of the studies they carried out in order to test the common sense teory of motion. That technique has shown to be useful when used on those studies.

The instrument

The interview protocol included 10 problematic situations whose correct resolution would require the use of the main newtonian concepts and laws. The situations addressed in the interview include the following phenomena:

a) An object at rest on another object, at the earth's surface - Book A
b) Motion due to an instant force, with friction - Book B
c) Free fall with initial velocity, at the earth's surface - Book C
d) Free fall from rest, in the air, near the earth - Spheres A
e) Free fall from rest, in a vacuum, near the earth - Spheres B
f) Vertical ascent due to an instant force, near de earth - Coin A
g) Free fall (after ascent) in the air, near the earth - Coin B
h) Uniform motion in the absence of air and gravity - Spaceship A
i) Uniformly accelerated motion in the absence of air and gravity, due to a constant force perpendicular to the direction of the initial velocity - Spaceship B
j) Motion after the withdrawl of the force referred to in i), in the absence of air and gravity - Spaceship C

Data collection

Students were individually interviewed on the 10 problematic situations by the second author. The interview took place in each subject's school and only the interviewer and the interviewee were present in the room. Each interview took from 45 to 60 minutes. All the interviews were audiotaped for later analysis.

Data analysis

After the transcription of the audiotaped interviews a content analysis of the students' answers was carried out in order to evaluate their consistency with the common sense theory of motion. Table 1 shows the fundamentals of students' answers which would enable us to classify their predictions/explanations as being in agreement with either the common sense theory of motion or with the newtonian mechanics (at the level required by the 10th grade syllabuses still followed in schools). Answers not included in the two models were classified as "other".

TABLE 1

Fundamentals for classifying students' answers

Problematic situation	Newtonian mechanics	Common sense theory
Book A	. 3rd law . Nule net force on the book	. Table supports the book . Nobody exerts effort on the book; The book does not produce effort; The book has no effort . Gravity keeps the book on the table; the book tends to fall; The table prevents the book from falling; It cannot pass through the table
Book B	. Slowing down motion . Negative acceleration due to friction book/table and air resistance (2nd law)	. Table supports the book . The effort initially given to the book is going to continually decrease; The book stops as soon as all the effort is used up . Weight, gravity, friction and/or motion use up effort
Book C	. Fall along a nearly parabolic path . Horizontal motion slowing down a bit (due to air resistance) and vertical speeding up motion (due to gravity minus air resistance)	. Fall due to lack of support, weight and/or gravity . Vertical path or horizontal (while effort is enough) followed by vertical path
Spheres A	. Vertical fall with accelerated motion . Falling time proportional to 1/a ("a" due to gravity minus air resistance)	. Fall due to lack of support, weight, gravity, air/oxigen . Falling time proportional to 1/W
Spheres B	. Vertical fall with accelerated motion . Falling time proportional to 1/g	. Fall due to lack of support . Falling time proportional to 1/W

Coin A	. Vertical slowing down motion . Initial velocity due to an instant force . Acceleration due to gravity and air resistance	. Motion takes place in the air . Coin gains effort when it is thrown up . Effort is used up to maintain the coin in the air, to keep going up, or due to motion, weight and/or gravity . The coin stops going up as soon as all the effort is used up
Coin B	. Fall due to gravity . Accelerated motion (due to gravity minus air resistance)	. Fall due to lack of support, weight and/or existence of air/oxigen
Spaceship A	. All engines off - nule net force (1rst law)	. Spaceship needs to produce a constant effort to keep the features of motion (engine N on)
Spaceship B	. Parabolic path . Constant horizontal velocity and increasing vertical velocity (1rst and 2nd laws)	. Motion perpendicular to the initial direction . Constant velocity (provided that K is constant).
Spaceship C	. Keeps moving on the direction it was going when the engine K was shut off . Constant velocity (1rst law)	. Stops (more or less rapidly) due to lack of effort . Falls due to lack of support

DISCUSSION OF RESULTS

Table 2 shows the students' performance on the 10 problematic situations included in the interview. The students' answers were classified taking into account the fundamentals presented in table 1.

TABLE 2
Students' performance on the problematic situations per school year and interview (f)

Problematic Situation	Common sense			Newtonian mechanics			Other		
	8th (n=15)	10th b. (n=14)	10th a. (n=14)	8th (n=15)	10th b. (n=14)	10th a. (n=14)	8th (n=15)	10th b. (n=14)	10th a. (n=14)
Book A	15	12	0	0	0	7	0	2	7
Book B	13	12	13	0	0	1	2	2	0
Book C	12	12	9	0	0	0	3	2	5
Spheres A	13	13	11	0	0	0	2	1	3
Spheres B	6	4	4	0	0	0	9	10	10
Coin A	15	13	12	0	0	1	0	1	1
Coin B	11	9	2	0	0	0	4	5	12
Spaceship A	12	10	10	0	2	4	3	2	0
Spaceship B	12	12	10	0	0	0	3	2	4
Spaceship C	3	2	0	0	2	7	12	10	7
Total: f	112	99	71	0	4	20	38	3549	
%	74.7	70.7	50.7	0.0	2.9	14.3	25.3	25.035.0	

Note: 10th b. - 10th grade before the teaching of mechanics
10th a.. - 10th grade after the teaching of mechanics

The analysis of the overall results presented in the table above enable us to conclude that:

a) One hundred and twelve (that is, 74.7%) of the 150 answers which should be obtained from 8th graders were classified as consistent with the common sense theory of motion; None of the answers given by these students could be considered as newtonian answers;

b) Ninety nine (that is 70.7%) of the 110 answers which should be obtained from the 10th graders, before the teaching of mechanics, were classified as consistent with the common sense theory of motion while only four answers (that is, 2.9%) were considered to be in agreement with the newtonian mechanics;

c) After the teaching of mechanics the number of answers in which 10th graders were consistent with the common sense theory of motion decreased to 71 (that is, 50.7% of the total number of answers they were asked to give) and the number of answers in agreement with the newtonian mechanics increased to 20 (that is, 14.3% of the number of answers expected from this group in the second interview).

The analysis of the results obtained with the two groups of students in the different problematic situations (table 2) shows that:

a) In all but the "Spheres B" and the "Spaceship C" situations the majority (or, in a few cases, the totality) of the 8th graders' and the 10th graders' answers compare to those expected from the common sense theory of motion;

b) After the teaching of mechanics, 10th graders kept on being fairly consistent with the common sense theory of motion in all but the "Spheres B", the "Coin B", the "Book A" and the Spaceship C" problematic situations. About 50% of the students showed a newtonian understanding of the two latter situations but no student did so regarding to "Spheres B" or "Coin B".

c) In the case of "Book A" and "Spaceship C" the fairly low consistency of students' answers with the common sense theory seems to be due to their learning of the newtonian explanation. However, this does not apply to "Spheres B" and "Coin B", as shown by table 2.

Therefore, although it seems that the common sense theory of motion could enable us to predict the majority of 8th and 10th graders' answers to the problematic situations included in the interview. There are some problematic situations in which students' explanations differ considerably from those expected from the common sense theory, without being consistent with the newtonian mechanics. It seems to us that the low predictive power shown by the theory in these cases can be explained by the fact that it is not sufficiently explicit about some aspects concerning free fall in the air and it hardly addresses free fall in a vacuum.

The analysis of the students' answers to the problematic situations including fall and an analysis of research done by others on free fall and gravity (e.g. Gunstone & White, 1981; Ruggiero et al, 1985; Mayer, 1987; Noce, Torosantucci & Vicentini, 1988; Franco, 1992; Galili, 1993; Reynoso et al, 1993) leads us to make the following proposal for a reformulation of the theory, in what concerns falling motion:

"The falling motion has an initial cause which may be lack of support and/or lack of effort to maintain motion without support. After being initiated, falling motion does not use up effort, contrary to other kinds of motion. This is the reason why it can be said to be a natural motion. However, a source of effort is needed to enable the velocity to increase during the fall. That source of effort can be the weight of the falling object, the air and the gravity. It is enough for the rate of effort to be constant (as the falling motion does not use up effort and, therefore, all the effort continuously supplied to the falling object is stored in it, originating an increase in its velocity). However, if the rate of effort increases (because the weight, the force of the air or the gravity, increase) it is even better because velocity can increase even more than in the previous case. In any case, the final velocity is as much larger as much higher is the fall.
In a vacuum objects can either fall or not fall, depending on whether the source of effort is the weight (a feature of the objects) or the air or the gravity (which do not exist in a vacuum). If there is no source of effort, objects float instead of falling."

Table 3 shows a reanalysis of the results considering the reformulation of the common sense theory presented above.

TABLE 3
Students' performance on the problematic situations per school year and interview, considering the reformulated common sense theory (f)

Problematic Situation	Reformulated C. S. T.			Newtonian mechanics			Other		
	8th (n=15)	10th b. (n=14)	10th a. (n=14)	8th (n=15)	10th b. (n=14)	10th a. (n=14)	8th (n=15)	10th b. (n=14)	10th a. (n=14)
Book A	15	12	0	0	0	7	0	2	7
Book B	13	12	13	0	0	1	2	2	0
Book C	12	12	9	0	0	0	3	2	5
Spheres A	13	13	11	0	0	0	2	1	3
Spheres B	11	8	6	0	0	0	4	6	8
Coin A	15	13	12	0	0	1	0	1	1
Coin B	14	12	12	0	0	0	1	2	2
Spaceship A	12	10	10	0	2	4	3	2	0
Spaceship B	12	12	10	0	0	0	3	2	4
Spaceship C	13	10	4	0	2	7	2	2	3
Total: f	130	114	87	0	4	20	20	2233	

%	86.7	81.4	62.1	0.0	2.9	14.3	13.3	15.723.6

Note: 10th b. - 10th grade before the teaching of mechanics
10th a. - 10th grade after the teaching of mechanics

Comparing the figures given in table 3 with those in table 2 one can conclude that the level of consistency between students' answers and the predictions from the common sense theory regarding situations "Spheres B", "Coin B" and "Spaceship B" has increased after the reformulation of the theory. In fact, in the overall, 86.7% 81.4% and 62,1% of the answers that should be given by 8th and 10th graders, before and after the teaching of mechanics, respectively, are consistent with the reformulated common sense theory.

Therefore, it seems that the reformulation introduced into the former version of the common sense theory has improved its predictive power, specially in what concerns situations which include motion in a vacuum.

CONCLUSIONS AND IMPLICATIONS FOR PHYSICS EDUCATION

Eighth grade students seem to be able to solve qualitative mechanics problems but when doing so they are fairly consistent with the common sense theory of motion. The study of the concept of force on the 9th grade and the study of mechanics on the 10th grade seems to have a meaningless effect on students' performance, as the majority of 10th graders' answers to the problematic situations included in the interview compare to those predicted by the common sense theory of motion. However, the fit between students' answers and the theoretical predictions has improved after the reformulation of the theory suggested above, specially for the situations including motion in a vacuum.

The results obtained with this study together with those from Ogborn's and his collaborators stress the hypothesis that an alternative theory to the newtonian mechanics may exist and that it is useful to their holders. If they feel happy with that theory in terms of explicative and predictive power, it should be expected that they do not fully reject it to acknowledge a new one (Posner et al, 1982) - the newtonian theory. It seems that students are able to correctly differentiate between contexts in which they must apply the accepted theories and contexts in which they may use the common sense explanations, even without being taught to do so. This may explain why the formal teaching has a meaningless effect on students' explanations, even for those who get high scores in physics.

Joan Solomon (1983a; 1983b; 1992) suspects that students will never be able to integrate the two explanatory models. Therefore, she has argued that students should be taught how to accurately descriminate contexts in which they must use the accepted theories from those in which they can apply the everyday models they believe in.

Before coming to eventually accept this argument, we would like to point out that in our opinion effort should be concentrated on the design of a new approach to the teaching of mechanics and on the evaluation of its efficacy regarding students' conceptual change. This approach should acknowledge both a constructivist perspective of teaching and learning and an evolutionary conceptual change model (Villani, 1992). It should also take into account the results of the studies on the origin of alternative conceptions on mechanics, emphasise a conceptual/qualitative approach (instead of a mathematical/quantitative one), integrate the study of kinematics and dynamics concepts and include several teaching strategies, materials and instruments in order to make it possible to deal with all the diversity of students' conceptions on mechanics. Moreover, this approach cannot take for granted teachers' preparation to promote students' conceptual change. In fact, P. Hewson and M. Hewson (1987) have argued that many teachers' conceptions of teaching are in conflict with the constructivist model and, as Mestre and Touger (1989) stated, "no major movement aimed at improving classroom instruction can be successful unless it is sustained by the day to day practices of the classroom teacher".

ACKOWLEDGEMENTS

Thanks are due to the ex-INIC, as it has sponsered the second author while this study was carried out. Also, the authors would like to acknowledge the schools and the students who participated in the study.

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