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INTUITIVE CONCEPTS AND FORMAL CONTENTS OF PHYSICS

by

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ABSTRACT

The analysis of answers given by students to certain Physics problems shows that behind the errors they make it is possible to identify a background of a Physics model currently referred to as intuitive which is different from the formal models built up by physicists.

The aim of this work is discussing results obtained from the analysis of answers to problems by Brazilian students from two different levels and several areas of knowledge.

In attempting to step beyond the knowledge of existing intuitive models which explain the unorthodox answers to Physics problems, several questions are proposed and new ways for going on with the research.

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INTRODUCTION

Research on teaching is generally directed towards meeting the needs of teachers and students regarding to the conditions in which teaching occurs and to the quality of the interaction between the subjects who participate in the situation.

Considerable amount of systematic work has been done in this field seeking solutions for specific problems that deal mainly with the most immediate aspects of teaching, such as the methodology used by the teacher, including the various forms of interaction between teacher and student, the kind of teaching material and the mechanism of evaluation.

A smaller amount of systematic work, on the other hand, has been made with the aim of solving problems which are less explicit in the process of teaching and learning. These problems correspond to the generally deficient knowledge of teachers and researchers on students' abilities for learning. The possession of mental structures, as defined by Piaget, on one side and the level of understanding of concepts to be worked out, on the other side, are essential factors for enabling an effective learning.

Our initial concern in this work is connected with the knowledge of certain conceptual structures regarding physics contents which would be present in students knowledge and which could define the starting point for teaching.

It is generally agreed among physics teachers that students have difficulties in dealing with some concepts in certain situations. It is observed on the other hand that these difficulties cause mistakes which are persistent and highly frequent in students answers.

Some research work has already been done in order to detect the concepts which would have been used by students and which could be responsible for a large part of their errors. These concepts have been called "intuitive", "spontaneous", "misconceptions", etc., by several authors and they can be interconnected in broader schemes forming intuitive models which may be capable of global explanations of physical phenomena.

In view of their broadness and interconnections these models form knowledge blocks with strong roots in students knowledge and their possession can explain the persistency of intuitive answers, even if formal concepts are taught.

An intuitive model for the concept of force has been worked out by Viennot[1] starting from students answers to a set of especially prepared questions which worked as traps for showing existent intuitive concepts.

The aim of this work is to perform an analysis of students mistakes in terms of global intuitive models which will lead to hypotheses about the context in which these intuitive concepts are emplaced.

The paper by Viennot presents some problems on mechanics which are capable of stimulating intuitive answers if the student has the corresponding intuitive concepts. The author does not go further in investigating what would favor the use of intuitive concepts although she points out that sometimes they appear mixed with the orthodox formalism.

Using two of the questions proposed by Viennot (see Appendix) the experiment was repeated with Brazilian secondary school students and with university students from several areas. The total number of students (184) was divided into two groups in order to simplify analysis and interpretation of results as

shown on Table I.

The necessary information is obtained with content analysis techniques, that is the analysis of students written material in solving the problems. The investigator main task is to find out significant categories for reconstructing the previously proposed framework representing the characteristics of the concept and which at the same time may contain the observations found in the raw material.

Taking into consideration that the investigator subjectivity could change the final results considerably, a system of referees was adopted for obtaining uniformity and coherence of the characteristics found and their classification.

It was found that, in general, the framework found by us was compatible with Viennot's model and that the intuitive characteristics which were searched were present in most of the tests.

Some of the answers were the following:

EXAMPLES OF STUDENTS ANSWERS

Answers to the 1st problem:

1 - "a) Different, for a larger elongation the spring exerts a stronger force

(There is a force that accompanies the object)

b) accelerations are different since at the same point their velocities are different"

(acceleration (or force?) is proportional to velocity).

2 - "a) Since amplitudes are different for the three cases, forces will also be different:

$$F = - k A \cos(\omega t + \phi)$$

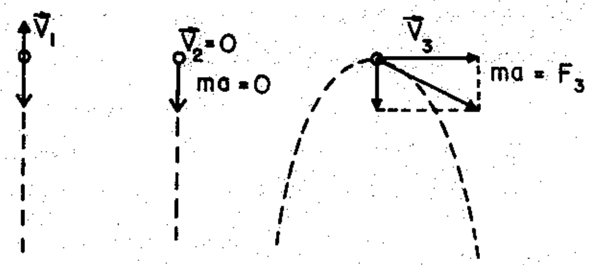
(there is a force that accompanies the object).

b) ... in case 3, the body is in equilibrium since $v_3=0$"
(zero velocity corresponds to zero force).

Answers to the 2nd problem:

3 - "No

$$F = ma = F_1 - P$$



(force in the trajectory direction).

4 - "$F = m\frac{d^2\vec{v}}{dt^2}$ since velocity (magnitude, direction and sense) is different for each at instant t the force will also be different for the six balls"
(force proportional do velocity).

5 - "In cases 1, 4, 6 the balls are under the action of two forces: the force with which they were thrown and their weight
(there is a force that accompanies the object).

Table I shows the distribution of the main categories for our sample, of answers which were considered intuitive and which are explained by the Viennot model.

It should be pointed out that in this work as well in that by Viennot separation of students in age groups has not been attempted and this corresponds to the intention of limiting the research, at least for the time being, to the construction of intuitive models, which explain physical phenomena, without

considering the possibility that they may change with age.

It would seem appropriate at this point to ask whether the origin of these answers could be in students understanding or in the questions which were made.

From the point of view of a research which tries to survey intuitive models which may be capable of explaining students mistakes and difficulties when using certain concepts the answer to the above question does not seem relevant. Starting from this information, the main scope for teaching is to be able to use a strategy based on intuitive concepts known in their details which can lead to students understanding of concepts as they are understood by physicists.

When analysing questions in relation to their physics content we conclude that they do not contain errors or deficiencies of meaning but only some elements which could be called "distractors" and their purpose is to bring out intuitive model which are in students minds. Furthermore, as it is widely known, most of these intuitive ways of thinking are in agreement with daily experience and teh common language used by people.

Although the sample which was used was not very large it is believed that results were significant enough for suggesting the deepening of a detailed model through a careful analysis of answers even before increasing their number. It is noticed immediately that the number of intuitive answers is considerably smaller for the group called "Exact Sciences" except for the Londrina Group and this discrepancy can be attributed to the lower level of that University in relation to USP.

INTUITIVE RELATION BETWEEN FORCE AND KINEMATIC VARIABLES

Some of the answers which were given to the problem relating force with kinematical variables seemed interesting:

"... velocities are different which implies in different forces".

"... acceleration at a given instant must be different since velocities are different".

"... since the force is $\vec{F} = m.\vec{a}$ and if velocities are different, accelerations are also different therefore forces are different for each of them".

"$\vec{a} = \frac{\Delta \vec{s}}{\Delta t}$ accelerations are different because in the same Δt the masses will have different displacements".

In trying to obtain deeper details of the models we noticed that there were subtle differences between answers which related force to velocity; this was evident in the way of reasoning followed by students until they established the relation between the two concepts. Next we became interested in the examples related to the concept of force connected to trajectory[2] and velocity; a large fraction of the answers were results of this unorthodox way of thinking about the concept of force, as it is shown on Table I.

On the other hand, we know that students use intuitive concepts mixed to the formalism taught at schools. In fact we detect this situation in many of the answers - the newtonian relation $F = ma$ appeared in certain phases of the resolution and the final result could be correct or not.[3]

What would the use of formal contents mean in the intuitive model of force?

What would be the depth of understanding with which

this content would have been used?

The answers to these questions did not seem simple to us but we directed our research towards them and tried to advance somewhat in relation to what had been previously established.

Examining carefully the intuitive answers which were included in the category $F = \alpha(v)$ we conclude that some of them could be detached from this group to form another category in which the relation between force and velocity would be the consequence of an intuitive relation between acceleration and velocity, completed with the formal newtonian relation.

We decided then to subdivide this category into others which could account for the cases which considered force as if it were proportional to velocity, $F = \alpha(v)$, in a relation without intermediate steps and those cases which dealt with a wrong concept of acceleration in its relation with velocity which was transferred to force through the relation $F = ma$. At the same time we started observing directly the intuitive relation between acceleration and velocity through implication relations such as: if velocities are different then accelerations will also be different.[4] Some other explanations which were given also showed that students were making a total confusion between the concepts of velocity and acceleration.

Returning to Table I we divide the first column into two categories and we add two others:

- $F = \alpha(v)$ in a direct relation
- $V \neq \rightarrow a \neq \rightarrow F \neq$
- $V \neq \rightarrow a \neq$
- Mixture of the concepts of velocity and acceleration,

and thus we obtained Table II.

Besides contributing for the improvement of the existing model and providing some information for studying conditions under which the formal content is used by students, these results show that the mistakes we detected in the answers which imply a proportionality relation between force and velocity may come from a different origin and in a teaching situation they must have a specific treatment when the aim is the correct and precise understanding of the concept.[5]

It was also noticed that after separating these two categories, the second problem (that of the jugglers) contributed strongly for the first category ($F = \alpha(v)$) while the first problem (that of springs) was contributing mainly for the others. This would already provide some information on conditions (type and content of questions) which would favor discussion of the physical concept in each of its characteristics.

Although results are not final, they point towards two new problems.

The first problem concerns to the choice between intuitive concepts and formalism which is made when students face a problem and this places the question:

What leads students either to use formalism, often without physical meaning or the intuitive concepts he has?

The second problem refers to the connection between the various intuitive notions and the formal relations for obtention of preferential reply paths.

The approach to both problems demands an elaboration of new instrument questions with which the required information can be obtained and this is the sequence that will be followed in a future research; meanwhile we merely intend to try to discuss the problems which arise in the research and raise hypotheses to be tested.

AN ATTEMPT FOR EXPLAINING THE USE OF INTUITIVE CONCEPTS AND FORMAL CONTENTS

At first sight it may seem that the student initial idea would be to use the concepts he has and that have physical meaning for him. However when his knowledge is limited by imprecise or incomplete concepts he searches "formulae" for solving problems.[5] It should be taken into consideration that when students were submitted to this test they were not under a common evaluation situation and often the contents were not part of their curriculum. Therefore we can assume that students were free to give intuitive answers which contained a physical meaning without fearing that there might be risks of undesirable consequences in the evaluation.

In trying to clarify the results and check the hypothesis we raised the answers relative to force were analysed separately for each problem, especially for that of the spring and that of the jugglers. The quantity and nature of the information given in the problem could be important factors in this question. The presentation of each of these problems is different in the representation of the real elements involved; a larger or smaller degree of "reality" apparent in the formulation of the problem could favor either the use of formalism or intuitive ideas.

Furthermore another factor seems to be decisive for the choice of intuitive or formal answers: the course students are taking.

Table III which refers to the São Paulo students shows the percentages of <u>yes</u> and <u>no</u> replies to the first question of the spring and jugglers problems which mean that forces are respectively equal or different.

The first outstanding result which however should be expected is that there was a higher percentage of correct answers from the Exact Sciences group. We consider that this group masters formal knowledge better and students are not involved easily by distractors which may be contained in the questions.

However, even for students classified into the Exact Sciences category there is a higher tendency of intuitive answers for the first problem (the spring) and formal answers for the second (the jugglers). We could justify this result considering that launching problems are classical and very common in Physics courses.

A second result is that for students included into the "other areas" category (mainly Biology and Psichology students) there is an inversion in the two problems regarding the higher tendency for intuitive replies: the jugglers problem is the one with higher percentage of intuitive replies. A hypothesis for justifying this result could be found in the presentation of the problem: the reality aspect presented in the problem would favor intuitive reasoning. This would suggest a research direction related to the preparation of questions which may bring forward intuitive conceptual structures.

In the jugglers problem velocity is given in the real movement representation (the trajectory is indicated in each case) and the question is about force. Therefore relating one concept to the other would be the most immediate operation without having to consider the acceleration which caused each trajectory. For the student, the aristotelic model $F = \alpha(v)$ would be able to explain each situation coherently.

In the springs problem there is information about velocity and force (suggested by the indication of equal elongations

and different amplitudes) for each case. In this problem the graphical representation of trajectory is not so clear and replies had to base on velocity and force data which were more explicit. It should be noticed here that the graphical representation of position in function of time does not correspond to the real trajectory.

The third result is that in view of the kinds of replies which were given we noticed that although intuitive replies occurred with different percentages for each of the two student groups they are not different regarding to the intuitive content and this leads us to emphasize that intuitive concepts of Physics are more widely established among students of areas other than exact sciences. This result suggests that we should work mainly with these students if we want to have more information about intuitive concepts.

Let us now come back to the content analysis of intuitive replies and the attempt of explaining the insertion of formal relations in intuitive reasonings.

For the spring problem, the percentage of correct answers is higher than for the jugglers problem and here students used $F = ma$ as an intermediate relation between v and F for concluding that the forces were different. It seems that the contradiction between the intuitive idea $F = \alpha(v)$ and the information that forces are equal led students to use a relation which would establish a bridge between the problem concrete known and the intuitive idea.

CONCLUSIONS

Within the physics teaching framework, we tried to study one aspect of the teaching and learning process which although little explicit is considered to be a decisive factor for the possibilities of effective teaching.[6]

In fact, we tried to understand what would be contained in students way of thinking in relation to specific contents and this will enable the preparation of problems with appropriate starting point and approach.

Furthermore since this area of research is still poor in adequate methodologies we outlined the path we followed in trying to solve an objectively stated problem showing the various branchings we had to face and which forced us to take decisions constantly.

Finally, new problems arised together with some replies for the initial problem. Some of these questions involved intuitive conceptions in the following aspects:

- the relation between the structure of intuitive conception and the subject knowledge area;
- a more refined elaboration of this conception and its relation to the type of question which favors its explicitation;
- the apparent coordination between intuitive conception and formal contents of a subject, that is the object of our present concern.

[1]Viennot, L., Le raisonnement spontanée en dynamique élementaire (Herman, Paris, 1979).

[2]M. McCloskey, A. Caramazza and B. Green, Science **210**, 1129 (5 December 1980).

[3]B.Y. White, Cognitive Science **7**, 41 (1983).

[4]See for ex.:

- R.J. Whitaker, Am. J. Phys. **51**, 352 (1983).
- D.E. Throwbridge and L.C. McDermott, Am. J. Phys. **49**, 242 (1981).

[5]J.A.G. McClelland, Eur. J. Sci. Educ. **6**, 1 (1984).

[6]J.K. Gilbert, D.M. Watts and R.J. Osborne, Phys. Educ. **17**, 62 (1982).

APPENDIX

Problem 1

Three identical vertical springs S_1, S_2 and S_3 exert a restoration force $F = -kx$ on three equal masses M at one of their ends. The spring elongation is x and k is a constant (fig. 1).

The three springs are attached to the ceiling and oscilate without damping about their equilibrium position with different amplitudes. At the instant t_o when the free end of S_3 reaches maximum height (with zero v_3 velocity) the ends of S_1 and S_2 are at the same height but with speeds v_1 and v_2 ($\neq 0$).

Answer in the table below whether the listed concepts are the same or different for the three springs.

	the same	different
a) Force exerted by the spring		
b) Total force acting over M		
c) Kinetic energy of M		
d) Potential energy of M		
e) Total energy of M		
f) Acceleration of M		

Why? (Reply for each question separately).

Problem 2

A juggler plays with 6 identical balls. At instant t all six balls are in the air at the same height following the trajectories indicated with dotted lines on the figure 2. The velocity of each ball at the same instant is also indicated on the figure 2.

1) The forces which act on these balls at this instant are

the same for the six?	different for each?	the same for some (which ones?)	different for others (which ones?)

Justify your answer (deleting air friction).

2) The same question for the six balls potential energy.

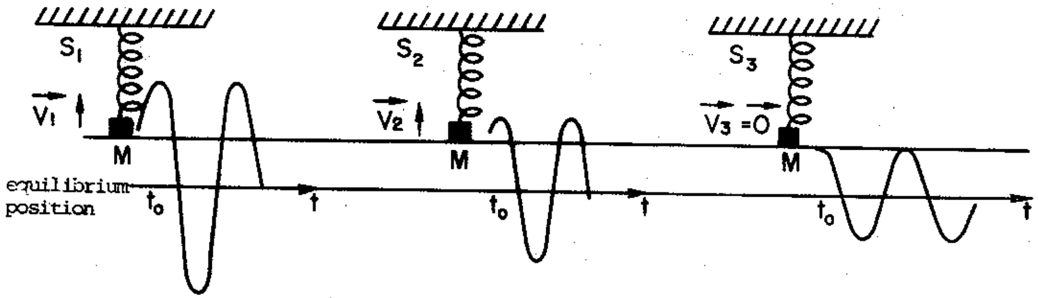


Figure 1 - Problem 1.

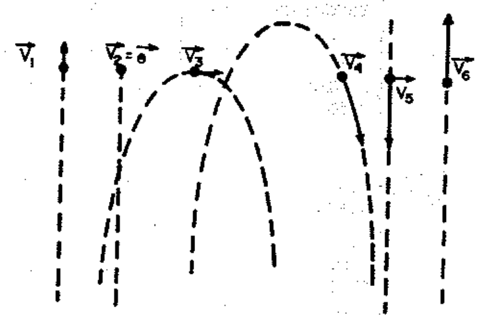


Figure 2 - Problem 2.

Table I. Distribution of answers over the main categories.

area	class		F=α(v)	Force in the trajectory direction	Force supply	Energy = α(v)	Force and velocity composition
Other areas	Last year of Secondary	14	7	5	3	3	–
	1st Biology (USP)	16	10	6	7	–	–
	2nd Psichology (USP)	16	14	8	2	3	1
	Summer Course* (USP)	12	14	1	1	–	1
	2nd Architecture (Londrina)	15	14	1	2	–	1
Exact Sci-ences	1st Physics (USP)	21	5	–	–	–	–
	2nd Physics (USP)	24	3	–	2	–	–
	3rd Physics (USP)	40	5	–	–	–	1
	4th Physics (USP)	14	4	–	–	–	–
	1st Chemistry (Londrina)	12	2	–	2	1	1

*Summer course offered by the University of São Paulo (USP) for secondary school Physics teachers.

Table II. Distribution of answers over the new categories.

area	class	F = α(v)	V ≠ → a ≠ → F ≠	V ≠ → a ≠	Mixture of velocity and acceleration
Other areas	Last year of Secondary	5	–	1	1
	1st Biology (USP)	6	1	3	–
	2nd Psichology (USP)	8	2	4	–
	Summer Course (USP)	10	–	3	1
	2nd Architecture (Londrina)	7	3	3	1
Exact Sciences	1st Physics (USP)	4	–	1	–
	2nd Physics (USP)	1	1	1	–
	3rd Physics (USP)	3	–	2	–
	4th Physics (USP)	3	–	–	1
	1st Chemistry (Londrina)	2	–	–	–

Table III. Percentages of yes and no replies to the first question of the two problems.

COURSES		Springs				Jugglers		
		Spring Force		Total Force				
		Yes	No	Yes	No	Yes	No	Some Yes
Other areas	Last year of Secondary	50	50	57	36	7	43	36
	1st Biology (USP)	44	50	38	62	24	38	38
	2nd Psichology (USP)	31	63	25	69	19	56	19
	Summer Course (USP)	50	50	34	66	34	33	33
	2nd Architecture (Londrina)	47	40	7	86	0	35	35
Exact Sciences	1st Physics (USP)	66	34	66	29	86	0	14
	2nd Physics (USP)	66	34	54	42	84	8	4
	3rd Physics (USP)	65	30	78	22	93	7	0
	4th Physics (USP)	71	29	71	21	100	0	0
	1st Chemistry (Londrina)	8	92	25	67	58	34	8