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SPONTANEOUS IDEAS ABOUT THE SPEED OF LIGHT

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ABSTRACT

The answers of a group of Physics graduate students to two problems on the speed of light are analysed. The results seem to confirm the use of spontaneous ideas which are very similar to those which form the "spontaneous" kinematics proposed by E. Saltiel of the University of Paris VII.

Some consequences related to the teaching of Physics and Special Relativity are discussed.

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INTRODUCTION

Recent research in the field of Science Education has been directed towards the detection and structure of students "intuitive" or "pre-scientific" concepts. The results which were obtained especially in Elementary Physics are promising and very helpful for understanding students mechanisms of thinking and the difficulties they find when they try to understand new Physics concepts (Workshop Proceedings, 1983). As far as the authors know, the problem of the influence of "spontaneous" ideas on the understanding of modern theories of Physics, which involve a higher degree of complexity and formalism, has not yet been studied.

This work intends to show how students who have already finished a Physics course use spontaneous notions in the solution of qualitative problems about the speed of light. It will be shown that these notions are very similar to those which form the "spontaneous" kinematics proposed by E. Saltiel (1978).

The article will be divided into four parts: the first will contain a synthesis of the main ideas concerning spontaneous kinematics, the second will present quantitative results on the answers to two problems on the speed of light and the third part will attempt to integrate the two previous parts in a model by analysing the main types of arguments used by students. Finally the content of the fourth part will discuss the implications for the teaching of Physics and Special Relativity.

1. SPONTANEOUS CONCEPTS IN ELEMENTARY KINEMATICS

The notion of independent and absolute motion permeates spontaneous kinematics: we can summarize it with the following characteristics

a) speed, the distance which has been traversed in a motion, and its trajectory are none of them dependent on the frame of reference;

b) motion is explained by a causal aspect in which a "motor" is associated with its real observable speed;

c) motion is explained by a descriptive aspect relating it to an absolute space. In this scheme there is only one true speed and one true traversed space and any differences in measurements obtained by various moving observers are caused by an "apparent" motion;

d) in situations with dragged motions, there is use of the idea of addition of absolute motions instead of transformation of a relative motion. Speed and real distances are seen as the additions of speeds and the "proper" distances traversed by the moving object and by the driving motor.

These characteristics can be complemented (Hosoume, 1984) with:

e) extension of the quality of being "proper" or "apparent" to the concepts of time and trajectory: the "proper" time would be that which is intrinsic to the motion;

f) existence of privileged observers with immediate access to the "proper" values of spatial and temporal parameters which characterize the motion.

2. QUANTITATIVE RESULTS

This section deals with quantitative results of answers given to questions in two problems about the speed of light. The text of the problems can be found in the appendix.

For simplicity, we will call the first "Problem about distance" (appendix A) and the second "Problem about time" (appendix B). They were given to students in individual interviews and interviewers took notes of answers.

2.1. PROBLEM ABOUT DISTANCE

This problem was given to twenty four graduate students. They all has a BSc in Physics and are presently engaged in MSc or PhD programs in Physics or Science Education.

An immediate interpretation of results presented in the table on distance (Table I) seems to indicate a partial concept of the invariance of the speed of light.

The answers to Q1 are compatible with the "spontaneous", galilean or relativistic views, although the latter implies that the frame of reference should be specified. However it is always possible to think of an implicit frame of reference.

Most answers to Q2 and Q3 are compatible with galilean invariance of distance and incompatible with the Special Theory of Relativity. But they are also compatible with an absolute spontaneous view.

Finally, most answers to Q4 seem to be incompatible with the galilean and with the relativistic view. Should we think that students change their interpretation of the phenomenon when they pass from one question to the other? Alternatively, we might hypothesize that they use a single, "spontaneous" concept, which is a view compatible with most student answers? The analysis of students explanations will help to answer these questions.

2.2. PROBLEM ABOUT TIME

This problem was answered by thirty students, whose background was similar to that of the previous group of subjects[1].

An immediate analysis of V, VI, VII and VIII in the tables on time[2] (Tables II and III) shows that about half of the students (in some cases a little more) answered in a way which is consistent with the relativity theory, but we will see later that the explanations they gave of their answers are less consistent with this theory. From the point of view of the invariance of the speed of light, speaking of the distance traversed by light or of the time spent for traversing is the same whatever is the frame of reference. However, comparing V

with VII and VI with VIII we notice some discrepancies. This suggests, according to our interpretation, the presence of ideas other than a direct relation between traversed distance and elapsed time, which seem to be stronger in students' knowledge. The answers which were incompatible with Special Relativity were compatible with Galilean Theory and with spontaneous kinematics (V - Table II). Some of the answers computed in VI - Table II seem to involve an "apparent time" concept which is related to the observer's motion (Hosoume, 1984). For students who use this concept the relativistic effects of lenght contraction and time dilation are combined in the final answer as it may be inferred from the justification which were presented.

The other results of VI could mean a classification of students answers partly in accordance with Relativity and partly in accordance with galilean time invariance, but VIII is clearer: it strongly suggests that time invariance coincides largely with a spatial invariance of traversed distance, a concept which is definitely not galilean.

3. ANALYSIS OF THE EXPLANATIONS

This section will present a synthesis of the ideas students gave to justify their answers.

3.1. THE DISTANCE PROBLEM

The answers to this problem are rather homogeneous, and seem coherent with a view of the "spontaneous" type: the symmetrical structure of the problem would favor this interpretation.

Let us consider some examples of answers to Q4:

- *"The differences (between the train and photon distances) are compatible with the speed of light invariance because the trains' positions do not change the speed of light and the distance between the photons and the trains depends on the train's path".*
- *"The invariance of the speed of light has nothing to do with the distance between the trains and the photons".*

The general idea is that the invariance of the speed of light means that light comes away from the antenna uniformly in all directions. The speed of trains being in opposite directions explains why the photons are not equidistant. Of course there are also occasional answers such as one which appeals to contraction of the distance $\overline{T_B B}$ or to dilation of the distance $\overline{T_B D}$ depending on the relation between the train and the photon direction.

If we pass to Q3 and Q2 we find:

- *"Train T_B is farther from D because besides the path of D there is also the path of the train itself".*
- *"Train T_D is closer to D and T_B is closer to B because of the invariance of the speed of light".*

All these answers look as if they are consequences of the idea of there being only one speed for the trains and for the light, as well as the idea of there being only one path: in this picture the distance between the trains and the photons as seen from the train does not seem to result from the transformation of a galilean invariant distance; rather it seems to be that distance which is the vector sum of the "proper" distances traversed by the photons and the trains. Thus for those who see speed and distance in an absolute way, it is not a problem that the text does not specify the framework, mention of it in the answers also being not considered necessary.

3.2. PROBLEM ABOUT TIME

The increase of the number of physical concepts involved in the problem and of the number of questions favor a dispersion of answers, and for this reason we will analyse them by parts, beginning with questions which refer directly to the influence of the rocket motion on the light path and on the time spent for traversing it. The explanations given which consider time and distance for forward and backward motion to be equal are obvious in the cases of Q1 and Q2, but not obvious for Q2 and Q6.

The following are some examples:

- *"The times for forward and backward motion are the same because of the speed of light invariance".*

- *"The antenna and the mirror keep the same distance in the forward and in the backward light path because it does not depend on the observer".*
- *"The light path as seen from the station is the same but only displaced".*
- *"For the station the light path is the same but the light beam is less intense because the rocket is farther".*

It seems clear that the implicit or explicit idea is that the forward and backward distance traversed by light is precisely the distance between antenna and mirror and the time is the same because the speed of light is invariant for both directions.

This kind of argument is still more explicit in answers to Q3 and Q4.

- *"The forward times are the same because the distances are the same".*
- *"The backward times are the same, because the speed of light does not depend on the frame of reference".*

But the unity of the distance traversed is not restricted to one particular type of reply: we can find it concealed also in "correct" answers to Q3 in which the forward time for the rocket is smaller than for the station.

In answering this question whith the theory of Relativity it is necessary to have two effects in mind. The main one is galilean, according to which the traversed distance depends on the frame of reference with a second which is

relativistic and depends on relativistic length contraction.

The latter effect opposes the former in the forward motion, and but has the same sign in the backward motion (Q4).

It is interesting to notice that many answers take into account <u>only</u> the relativistic effect, ignoring the Galilean aspect.

- *"Light spends a longer time for the rocket forwards and backwards because of length contraction for the station".*
- *"Light spends a longer time for the station forwards and backwards because of time dilatation".*
- *"In the forward motion light spends a longer time for the station because there is contraction for the rocket".*
- *"For the rocket, light spends a longer time in the backwards because of the length contraction when the direction is the same".*

It is easy to see that for last three students the relativistic effect is inverted in the forward motion: the contraction of distance happens for the object that is moving, that is the rocket, and not for the observer. Similarly, time dilation has nothing to do with the measurement of only one clock.

All this seems very coherent with the characterization of the motion as "absolute", and with an "absolute" view of relativistic effects.

A confirmation of the "absolute" motion may be found in justifications such as:

- *"For the rocket light spends a longer time forwards, because of antena's displacement. For the station the situation is the same".*

Another idea that is rather frequent is that of compensation.

- *"On coming backward light spends a longer time for the rocket so as to compensate the invariance of the total time".*
- *"For the rocket, light spends a shorter time forwards because of the contraction and a longer time backwards because of the dilation of distances in opposite direction to the motion. But the total is the same for both observers".*
- *"Apparently for the station light spends a longer time forwards than backwards but the total is the same as for the rocket".*

Some original ideas are also present:

- *"Time passes more slowly in the rocket but the distance traversed by light is shorter, this compensates the fact that time passes faster in the station for which the distance is longer".*

Finally, we should mention the presence, often openly but sometimes subtle, of the qualifications "real" and "apparent" given to time and distance. In general the argument is always the same: the two observers "seem" to make different measurements but "really" there is only one measurement of space, of time and of the speed of light[3].

We could therefore, have called this section of the paper "The absolute scale".

First, there are many answers for which everything is fixed and everything is identical: forward and backward time, light path, and speed of light. There is only one physical reality characterized by parameters which are independent of observers. Then we have answers in which there is a compensation expressed in various ways: contraction and dilation of distance and time. In conclusion, although details may be different, global time and distance must be independent of the observer.

Next there are answers in which the differences between the various observers are due only to relativistic effects: the phenomenon is essentially equal for all observers. It is thus easy to use the last argument: it is true that measurements are different because of relativity but in fact they are only "apparent" effects. The real values, that is, real distance, real speed, and real time are unique because they do not depend on any observer.

Unfortunately the students' answers do not supply any indication of the relation between the "real" parameters and the observer so as to identify privileged observers.

4. COMMENTS AND CONCLUSIONS

It seems that the idea of absolute motion is a promising starting point for interpreting undergraduate and graduate students' answers when the situation involves several observers.

This may lead to some implication for the teaching of special relativity: in particular, the fact that it is not realistic to take for granted that students have understood Galilean relativity completely. In our opinion, the teaching should start farther back, and go more deeply, so as to "build" first a Galilean intuition which will at least in part liberate students from the idea of an absolute frame. The work of building a relativistic intuition should start only after students think and "see" in the Galilean way, since special relativity is much more abstract because it is even more relative, and more difficult to appreciate because it cannot be supported by everyday life experience. Some help for this difficult task can be provided by the use of simple qualitative problems and "thought experiments" of the type of "paradoxes".

But we believe that the idea of absolute motion, is much deeper and can also help us understand students answers in other fields of Mechanics (Villani, 1984) which involve relations between the concepts of force, trajectory, velocity and acceleration.

If we examine the history of Physics even superficially we find an idea of motion which is similar to that of our students. Let us begin with the primitive ideas of motion and of change in ancient Greece until the sophisticated ideas of the identification between matter and motion in the aether theory (Doran, 1976) or the wave nature of matter.

This suggests at least as a matter for reflection

that the students spontaneous ideas are not merely tares which must be eliminated but that on the contrary they contain "wheat" which must be cultivated. They reflect in some way the fundamental concepts of nature and also the intuitive models that are the basis of modern theories, which are however complicated from the point of view of mathematical formalism. The water which may help the growth of this "wheat" is the study of the history of ideas in Physics, through which students can become conscious not only that Physics is not made up of mathematical formulae only, but also that Physics is close to Philosophy and to the culture of its time.

In the specific case of the theory of relativity, we believe the study of its origin, its development and the relation with the Lorentz theory could help not only to eliminate many myths concerning its historical necessity (La Forgia, 1979), but could also lead to better understanding of the peculiarities of Einsteinian ideas. And all the story of the aether, especially from Faraday onwards, will help students not only to understand their "tendency" towards the absolute but also to reconcile them with some very simple ideas of General Relativity and the modern Field Theories.

In conclusion we can summarize our aims in the study of students' spontaneous ideas as follows: Physics teaching will profit greath if the discussion of the fundamental concepts can be associated with their historical analysis and to the consciousness of spontaneous concepts. Students will not only become more conscious of their knowledge, more cultured and better prepared for teaching, but also will probably become more easily able to "think" in Physics.

The authors acknowledge Dr. Edith Saltiel for her comments and Dr. Jon Ogborn for his suggestions.

APPENDIX A - PROBLEM ON THE DISTANCE

On the instant in which the two trains T_B and T_D which travel with speed $v = \frac{C}{2}$ in opposite directions cross the antenna A, it emits two light signals B and D with opposite directions. Train T_B and signal B have the same direction and a similar situation for T_D and D (Figure 1).

QUESTIONS

Q1. At what distance from A will the two trains T_B and T_D and the signal D each be when B crosses an antenna A' that is at distance L from A? Why?

Q2. Suppose you are a passenger in T_B. For you, when B reaches antenna A' which of the two light signals will be closer to you? Why?

Q3. Suppose you are a passenger in T_D. For you when B reaches antenna A' which of the two light signals will be closer to you? Why?

Q4. Are your answers to the previous questions compatible with the speed of light invariance? Justify your answer.

APPENDIX B - PROBLEM ON THE TIME

A rocket with length L is provided with an antenna (A) in its rear part and with a mirror (M) in the front part. When the rocket which travels with a speed which is half the speed of light passes over a terrestrial station antenna A emits a light signal that after reaching the mirror (M) is reflected returning to the antenna (A) where it is absorbed (Figure 2).

QUESTIONS

Q1. For somebody in the rocket, does the light signal spend a longer time to go from the antenna (A) to the mirror (M) or in the return from the mirror (M) to the antenna (A)? Why?

Q2. For somebody at the terrestrial station does the light signal spend a longer time to go from the antenna (A) to the mirror (M) or to return from the mirror (M) to the antenna (A)? Why?

Q3. Does the light signal spend a longer time for traversing the distance A-M for somebody in the rocket or for somebody in the station? Why?

Q4. Does the light signal spend a longer time for traversing the return M-A for somebody in the rocket or for somebody in the station? Why?

Q5. Draw a diagram showing the light path, from the antenna to the mirror and return, as seen by somebody in the rocket. Explain your drawing.

Q6. Draw a diagram showing the light path from the antenna to the mirror and return, as seen by somebody in the terrestrial station. Explain your drawing.

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FOOTNOTES

1) The type of answer and explanation presented in this problem are similar to those given by other 30 students to another problem in which the antenna and the mirror where attached to the terrestrial station.

2) The answers to Q5 and Q6 are drawings with comments. VII and VIII in this table were constructed from the comparison between all the drawings.

3) The use of the "real" and "apparent" categories for relativistic problems was noted by several authors such as Angotti (1976) and Hewson (1982).

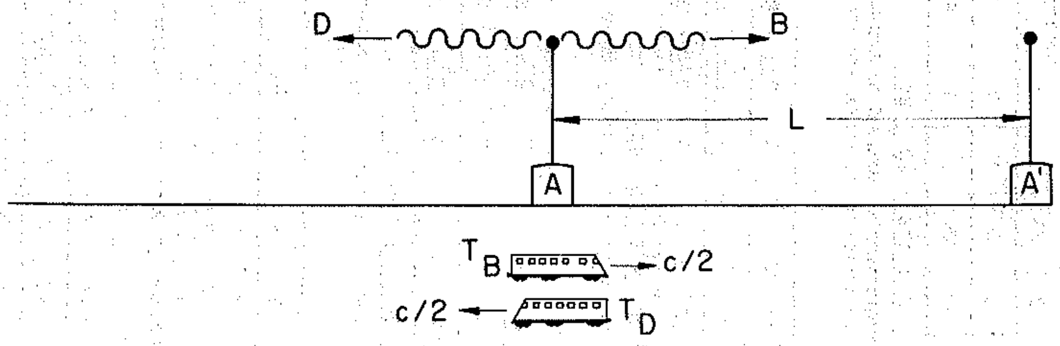

Figure 1

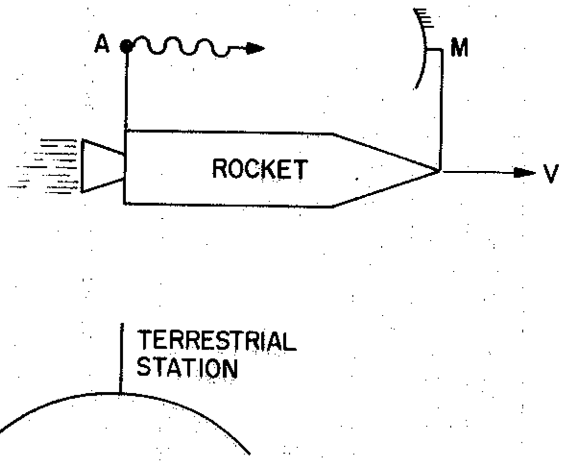

Figure 2

TABLE I – RESULTS ON PROBLEM ABOUT DISTANCE

I. Comparison between the distances for photons and trains (Q1)

	SR	GR	S_pK	N
$\overline{BA} = \overline{AD}$	A	A	A	24
$\overline{T_BA} = \overline{T_DA}$	A	A	A	24

Indications of the frame of reference

	SR	SR	S_pK	N
Yes	NE	NE	C	3
No	NE	NE	A	21

SR = Special Relativity

GR = Galilean Relativity

S_pK = 'Spontaneous' Kinematics

A = Affirmed by

NE = Not Excluded by

C = Contradicts

II. Distance for photons as seen from train T_B (Q2)

	SR	GR	S_pK	N
$\overline{T_BB} < \overline{T_BD}$	C	A	A	20
$\overline{T_BB} = \overline{T_BD}$	A	C	C	4
$\overline{T_BB} > \overline{T_BD}$	C	C	C	–

III. Distance for photons as seen from train T_D (Q3)

	SR	GR	S_pK	N
$\overline{T_DB} > \overline{T_DD}$	C	A	A	20
$\overline{T_DB} = \overline{T_DD}$	A	C	C	4
$\overline{T_DB} < \overline{T_DD}$	C	C	C	–

IV. Coherence with invariance of the speed of light (Q4).
Asymmetry of photons is compatible with the speed of light invariance.

	SR	SR	S_pK	N
Yes	C	C	NE	11
No	A	A	C	7
No Relation	C	C	NE	6

TABLE II – RESULTS ON PROBLEMS ABOUT TIME (Q1 to Q4)

V. Comparison between the forward and the backward time (Q1 and Q2)

Observarions in the Rocket					Observations in the Station			
Number	SR	GR	S_pK		Number	SR	GR	S_pK
7	C	NE	NE	$\Delta t_f > \Delta t_r$	16	A	NE	NE
21	A	NE	NE	$\Delta t_f = \Delta t_r$	13	C	NE	NE
2	C	C	C	$\Delta t_f < \Delta t_f$	1	C	C	C

Δt_f = time spent in the forward displacement A-M.

Δt_r = time spent in the return M-A.

NOTE: The notations about previsions are the same of Table I.

VI. Comparison between the Rocket time and that of the Station (Q3 and Q4)

Forward					Backward			
Number	SR	GR	S_pK		Number	SR	GR	S_pK
3	C	C	NE	$\Delta t_R > \Delta t_S$	15	A	C	C
9	C	A	NE	$\Delta t_R = \Delta t_S$	8	C	A	NE
18	A	C	C	$\Delta t_R < \Delta t_S$	7	C	C	NE