Third International Seminar

MISCONCEPTIONS AND EDUCATIONAL STRATEGIES IN SCIENCE AND MATHEMATICS

AUGUST 1-4, 1993

Department of Education
New York State College of Agriculture and Life Sciences
CORNELL UNIVERSITY
Ithaca, New York

Seminar Office: 101 Kennedy Hall
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Article Title: Spontaneous reasoning of secondary school teachers about the relativity of mechanical magnitudes

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Keywords: concept formation,teacher education,theories ,misconceptions,abstract reasoning,teachers,cognitive processes,inservice teacher education,relativity

General School Subject: physics

Specific School Subject: mechanics

Students: student teachers

Macintosh File Name: Valadares - Spontaneous Reason

Adjusted File Name: Valadares-SpontaneousReason.sit.hqx

SPONTANEOUS REASONING OF SECONDARY SCHOOL TEACHERS ABOUT THE RELATIVITY OF MECHANICAL MAGNITUDES

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Abstract

Some characteristics of spontaneous thinking in physics students, in relation to kinematics, were reported by Saltiel and Malgrange in 1980. One of them is this: ***speed, the distance which has been traversed in a motion, and the trajectory of a moving object are viewed as independent from a frame of reference.***

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At the end of two formative courses on special relativity, we gave in greater Lisbon, we had the opportunity to administer the two Villani and Pacca' problems and another question on the relativity of motion. The answers of 53 secondary teachers with a wide range of experience in teaching (varying from 39 years of teaching to 1 year) were analyzed and we found the same kind of spontaneous thinking as observed in the Brazilian students.

This communication intends to report this research involving Portuguese Physics teachers, divulge its results, and to make some considerations on the teaching of the relativity of mechanical magnitudes.

Introduction

We think in concepts establishing complex relationships with them. As a consequence of the experiences that we have, the network of conceptual relationships that we establish in our minds can imply scientifically incorrect reasonings, because of deficient construction of concepts and/or by insufficient or incorrect relationships. When this happens, those scientifically incorrect reasonings last longer than we would hope.

The history of science is rich in incorrect conceptual relationships that have lasted many centuries; on the other hand, thousands of classroom investigations have shown an enormous persistence of ingrained thinking of students more or less separated from those that are accepted by current science. These ingrained ideas have empirical foundations, being supported by their living experiences.

Some kinds of Physics students' reasonings have revealed such uniformity, with respect to countries, schools, methodologies of learning and students' ages, so that we suppose those reasonings are supported in conceptual frameworks that are well defined and clearly opposite to the scientific frameworks.

Concluding about the existence of some universal structures in the students' spontaneous thinkings about the kinematic situations, Saltiel and Malgrange (1980, p. 73) pointed out some characteristics of *spontaneous concepts in kinematics.* One of them, for example, is this:
The speed of a body, the distance it travels and the trajectory it describes are viewd as independent from a frame of reference.

At first glance it looks superfluous to investigate to what degree this spontaneous thinking of students is extended to teachers. It seems evident that teachers, being used to solving problems about galilean relativity, must consider the velocity as a relative magnitude, consequently admitting different distances in different inertial frames. But the research that has been made with students that have studied Physics for many years, and the research with teachers that are involved in their initial training, has taught us not to be confident about such "evidence". As a matter of fact, these students and teachers construct their thinkings very well, using only scientifically correct ideas, when they are confronted with *routine situations*.

Nevertheless, when they have to solve *new situations*, they often use ingrained ideas that are clearly *misconceptions.*

For instance, A. Villani and J. Pacca (1987, pp. 55-66) made a study in Brazil with graduate students in Physics involved in post-graduate courses, and they detected the persistence of spontaneous conceptions that were analogous to those that were manifested by secondary school students, and whose characteristics were pointed out by Saltiel and Malgrange.
So, why not investigate if the same kinds (or other kinds) of conceptions are spontaneously used by the teachers in secondary schools (with more or less experience about Physics teaching) when they analyze unfamiliar situations?

In 1992 we gave two short courses (twelve hours) on special relativity that were designed for the preparation of Physics (and Chemistry) secondary school teachers. In the first course (in a town south of Lisbon) 23 teachers participated, and in the second (in the city of Lisbon) 30 teachers were present.
At the end of these two formative courses, we had the opportunity to administer the two Villani and Pacca' problems and another question about the relativity of motion. The answers of the 53 secondary school teachers with a wide range of experience in teaching (varying from 39 years of teaching to 1 year, and from one level to all the five levels of basic and secondary school Physics) were analyzed.

Almada: 23 teachers ; *Lisbon*: 30 teachers

	1-5 years	5-10 years	10-15 years	15-20 years	20-30 years	30-40 years
1 level						
2 levels	1	1		1	1	
3 levels	2		1	1		
4 levels		2	2 3	1 7	1	
5 levels		2 4	3 1	6 2	2 7	2

This communication intends to report this research, to divulge its results, and to make some suggestions about the teaching of relativity of mechanical magnitudes.

Methodology of the research

The *program* of the course was this:

1. The crisis of ether in classic Physics and the theory of relativity as the only possible way out (3 hours).
2. Some fundamental notions of relativistic kinematics (3 hours).
3. The relativistic dynamics and the notions of mass and energy (3 hours).
4. Alternative conceptions in relativity (3 hours).

The first three points were discussed (with questions and little dialogues). In the last point it was administered a written instrument of research that was kindly and responsibly responded to by all the teachers. At the end there was a profitable collective debate about all the questions. The instrument had 8 questions on the speed of light and the change of frame of reference: the first seven questions were created by J. Villani and J. Pacca and they belong to their research instrument which was administered by them in Brazil; the last question was written by us and designed to reinforce, if possible, the investigation of an answer for this focus-question:

To what extent do Portuguese Physics teachers have the same kinds of spontaneous reasonings revealed by Brazilian graduate students?

The answers were carefully analyzed so as to try to discover the kind of reasoning used: einsteinean, galilean or spontaneous

If there is a reasoning based on *einsteinean relativity*, then some characteristics will be present, say:

- choice of the convenient inertial frame without any kind of bias to earth frames or other frames;
- constancy of light speed in all inertial frames and the assumption of its finite character;
- relativity of all the other velocities, times, and distances traversed by bodies;
- adequate use of Lorentz equations.

When we are in the presence of a reasoning supported by *galilean relativity*, the characteristics will be:

- choice of an inertial frame but the assumption of an absolute frame, the only one where light travels at the same speed in all directions;
- variability of the speed of light in all inertial frames, except in the absolute frame, and no assumption of the finite character of light;
- relativity of the velocities of bodies and the distances which they traverse in motion; no relativity of spatial distances and time;
- adequate use of galilean equations.

Finally, the reasoning supported in "*spontaneous kinematics*" will be evident when we can verify some characteristics:

- no choice of frames, and a tacit adoption of earth frames, or a space absolute frame, where the biased observer of real, proper or truth values is situated;
- no assumption of the finite character of light speed;
- privileged velocity in the earth frames, or in other frames assumed as absolutes; no relativity of time, spatial distances and distances traversed by bodies;
- inadequate use of transformation equations.

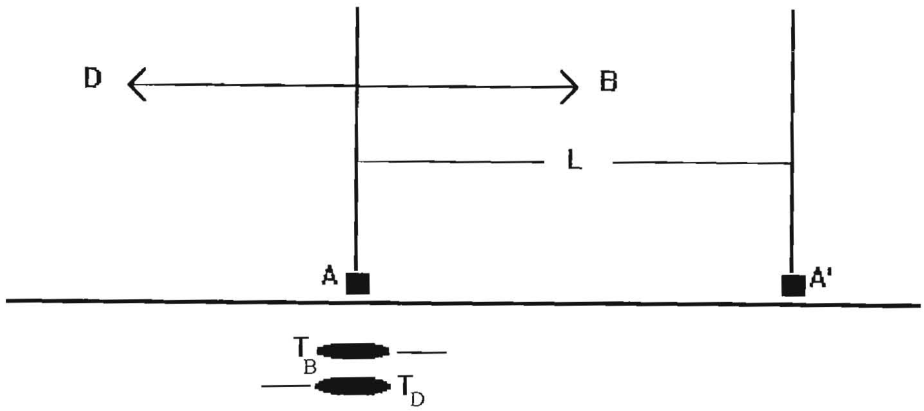
We tried very hard to discover a predominance of some of these characteristics.
As we had teachers who graduated in different subjects (Physics, Chemistry, Physics and Chemistry, Chemical Engineering and Pharmacology), we began making separated analyses considering the different variables: geographical area, experience, and kind of academic education, say, the subjects of the degrees teachers held. This detailed work led us to many separate annotations and many tables. A careful comparison of all the tables and annotations, and the fruitful discussion that happened at the end of the course, permitted us to infer this first and important conclusion:

The geographical area, the experience, and the kind of academic education did not reveal any significance in respect to this work. Apart from the self confidence shown (or not) in some teachers' replies, and the more or less formal correction of this or that answer, the kinds of responses were quite similar and revealed the same kind of omissions and misconceptions.

Some results of research

1-First physical situation

At the moment at which the two trains, T_B and T_D , which travel with speed v = c/2 in opposite directions, cross the antenna A, it emits two light signals, B and D , in opposite directions. Train T_B and the signal B travel in the same direction and so do T_D and D.



Second question- comparing distances traveled by photons as seen from train T_B

This question needs a change to frame T_B . In the same way as with the Brazilian students, almost all the answers of Portuguese teachers were incompatible with einsteinean relativity. In fact, *48 of the 53 teachers concluded that signal B was nearer.*

	SR	GR	S_DK	N_A	N_L	N_P	N_B
$T_BB<T_BD$	R	A	A	19	29	48	20
$T_BB=T_BD$	A	R	R	4	0	4	4
$T_BB>T_BD$	R	R	R	0	0	0	0

Some of the reasons presented that signal B was nearer revealed that most of the teachers maintained the relativity of the speed of light, and not only believed but promoted the earth frame as an absolute frame. One of the answers, for example, was this:

"Signal B is nearer because its direction is the same as the vehicle T_B's direction, in which I travel."

Only a few answers revealed clear galilean reasoning (in one of them he velocity c/2 was computed , as being the velocity of light, with the application of the galilean rule for composition of velocities). *The majority of teachers only presented the idea that T_B pursued the luminous signal,* and this could mean a spontaneous and not a relativistic reasoning, based on the composition of absolute distances traversed by particles (including photons). A teacher, for instance, presented a scheme of trajectories from which he concluded:

"The distance between signal B and T_B is l/2".

In spite of the fact that this question is very easy, there were many reasonings that revealed the difficulty teachers had to transfer their knowledge to the conceptual network of special relativity. For example, the reasoning contained in this answer:

"The distance of T_B shortens but T_B moves with time dilation".

In fact T_B moves on the earth, but does not move in the frame connected to T_B . There is a «contamination» of frames resulting in a bias towards the earth frame. To speak in a time dilation, we have to think as an earth observer, and about the events that happen in the frame T_B . Therefore, the observer is in frame T_B (and not on earth) and the motion occurs on the earth (and not in T_B).

This «contamination» of frames , with unconscious sliding from the frames in motion to the frames on the earth, occurred many times in the resolution of the problems, and also happened in the final discussion, at the end of the course.

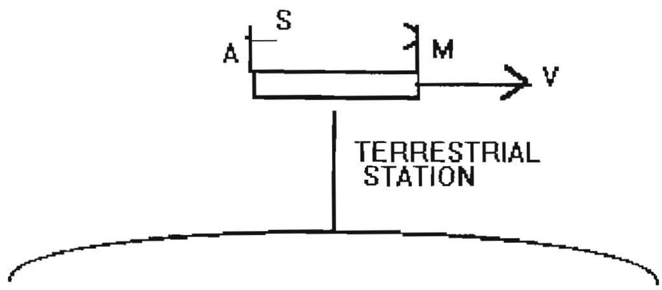
Third question - comparing distances traveled by photons as seen from train T_D

The answers to this question were compatible with the answers to the previous question:

	SR	GR	S_DK	N_A	N_L	N_P	N_B
$T_DB>T_DD$	R	A	A	19	27	46	20
$T_DB=T_DD$	A	R	R	4	0	4	4
$T_DB<T_DD$	R	R	R	0	0	0	0

2-Second physical situation

A rocket of 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 at a speed which is half the speed of light, passes over a terrestrial station, the antenna emits a light signal, S , which, after reaching the mirror, is reflected and returns to the antenna where it is absorbed.



Fifth question- comparing the forward time (Δt_f) and the backward time (Δt_b) of the signal in the earth frame

In this question, the length of the rocket is contracted in the earth frame, but the most important aspect is the fact the forward trajectory traversed by light is greater than the backward.
Then, the result is $\Delta t_f > \Delta t_b$.

	SR	GR	S_pK	N_A	N_L	N_P	N_B
$\Delta t_f > \Delta t_b$	A	NR	NR	11	11	22	16
$\Delta t_f = \Delta t_b$	R	NR	NR	8	2	10	13
$\Delta t_f < \Delta t_b$	R	R	NR	3	14	17	1

The first aspect to raise is the great number of teachers that responded incorrectly that $\Delta t_f < \Delta t_b$. The analyses of justifications, and the final dialogue, permited us to conclude that many of them used a composition of velocities based on a *emission theory of light.* For example this answer:
***" It takes more time to go from M to A, because the distance is the same and the velocity is less".* The velocities c+c/2 and c-c/2 were computed by using the classic rule of velocities composition.**

These *emission theories of light* have their history in a period when scientists tried to solve the problem of the negative result of the Michelson-Morley experiment, without abandoning the conceptual framework of classic mechanics. These theories failed as a consequence of the observation of binary stars, and as a result of the experiments of interferometry with extra-earth light. Then, in this situation, the forward velocity of light would be $c+v_A$, as photons and antenna A move in the same direction, and the backward velocity of light would be $c-v_M$, as photons and mirror M move in opposite directions.
We think this is an interesting example of the existence of some similarities between the spontaneous reasoning of students and teachers, and the scientific ideas throughout the history of science.

Many answers contained, implicitly or explicitly, the idea that the length of the rocket was precisely the distance traversed by light (as in the rocket frame- previous question). This was assumed as an absolute distance. We choose these two examples:
"The justification (for $\Delta t_f = \Delta t_b$) is the same as I presented in the previous answer (that is, the distances traversed by light are equal from A to M ,and from M to A , and the velocity of propagation of signal is the same)".
"The same as in the previous question: the time is equal, as c is constant and the distance traversed also is constant".
This kind of reasoning was similarly detected by Villani and Pacca in the Brazilian students (1987, p. 62).

We detected three answers from teachers with very different backgrounds where the justification for $\Delta t_f < \Delta t_b$ was the same:
"The luminous signal is going away from the earth observer".

Some teachers can remove themselves from these kinds of misconceptions, when they dominate the Newtonian mechanics, but they still fall into them when they penetrate into more formal, and less known, conceptual fields (as in the case of einsteinean relativity). This was shown by answers as this:
"It takes the same time, in accordance with the theory of relativity. Intuitively, I would think the opposite, that is: in the traject from A to M, in accordance with classical mechanics, when the rocket goes forward, the mirror M should go away; then, light should take more time to reach M . Inversely, in the return traject, from M to A, it is the back of the rocket that approaches the reflected luminous signal, and then, it should take less time."

It happens the same with secondary school students, but for these, quite often it is unnecessary to reach such a formal field.

We detected the same inversion of frames and relativistic effects that Villani and Pacca had verified with Brazilian students (1987, p. 62). For instance:
"It takes more time to go from A to M because the length of the rocket becomes longer than L for me, as I'm on the station".
For the observer on the station the length becomes shorter, as a consequence of space contraction.

Seventh question- comparing the rocket time ($\Delta t'_r$) and the earth time (Δt_e)of the signal in the backward motion

The distance traversed by the luminous signal is clearly less to the station observer, not only because he watches a contraction of the rocket's length, but also because he watches the antenna running into the signal. Nevertheless, in the majority of the answers we read that "*time is greater to the earth observer*".

	SR	GR	S_DK	N_L	N_A	N_P	N_B
$\Delta t'_r > \Delta t_e$	A	R	NR	11	6	17	15
$\Delta t'_r = \Delta t_e$	R	A	NR	0	3	3	8
$\Delta t'_r < \Delta t_e$	R	R	NR	12	14	26	7

Why did this great percentage of wrong answers happen? In our opinion, the main reason is the fact that many teachers repeated the same spontaneous reasoning that they had developed in the previous question (comparison of the rocket time and the earth time of the signal in the forward motion). So, eight teachers used, once more, only the time dilatation, and three teachers used only the contraction of space. Three teachers used the same justification based on the constancy of light speed, and the same hybrid reasoning with different velocities of light in different frames was used once more .
Furthermore, we think that the fact that many answers had the words "*by the same reason*" is very significant.

Commentaries, conclusions and suggestions in short

The history of science shows us the difficulty scientists have had to get rid of a geocentric and homocentric position in the face of the interpretation of events, particularly the motion of celestial bodies. How can we be respected when teachers spontaneously bias the earth frames as opposed to all the others?

The history of special relativity reveals to us that extraordinary scientists (Lorentz, Poincaré and others) were not able to liberate themselves from the conception of absolute space, trying to solve the difficulties built up by the negative result of the Michelson-Morley experiment in the framework of absolute motion. How can we be admired when teachers tend to describe the motion in an absolute space, and to be in favor of one distance, and of one trajectory, against all the others that are involved in the situation?

This research permitted us to conclude that not only do students maintain spontaneous ideas centered in the concepts of absolute motion in a "latent state" (Villani and Pacca, 1990), but so do the secondary school teachers, regardless of their experiences. Quite often, the teachers end up mixing these spontaneous ideas (whose characteristics are amongst the ones that Saltiel and Malgrange systematized in 1980) with relativistic ideas, sometimes hiding them in a technical language, resulting in unacceptable hybrid reasonings.

This research has depressed the author, who has fought in his country to update the teaching of Physics in secondary schools with the introduction (in the last year- the 12th year of education) of an approach to special relativity. In consequence of what we could verify in this research, it is our opinion that the introduction of a subject of special relativity (without prejudice of other more basic subjects) requires a previous instruction of teachers, not only in the field of special relativity itself, but also in the field of galilean relativity. The mastering of this theme is a pre-requisite to einsteinean relativity.

Moreover, galilean relativity is very good when discussing real and conceptual experiments of relative motion, and when confronting personal, idiosyncratic, spontaneous teachers' ideas with the experimental evidence, trying to liberate the teachers from all kinds of misconceptions related to absolute distances traversed by bodies, and absolute velocities. Only after that, with a solid penetration in the special relativity field, could they liberate themselves from the spontaneous idea of the infinite light velocity, and the old conception of absolute time, without falling into reasonings outside the proper ground of galilean relativity.

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