The use of the Principle of Relativity in the interpretation of phenomena by undergraduate physics students

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This research is based on the analysis of answers given by undergraduate physics students when confronted with situations related to the Special Theory of Relativity. Historical and epistemological studies indicate the importance of principles for the construction of physical theories. There is a consensual acknowledgement of the fundamental role played by the Principle of Relativity in the case of Special Relativity. The study investigated to extent to which that principle was employed by the students when dealing with a diversity of phenomena. The research data were obtained through clinical interviews and supported two main conclusions: a) the Principle of Relativity is not used as a heuristic tool in the students' answers; b) the situations presented were not regarded as "problematic" by the students, who did not feel the need to use interpretative structures other than those of classical mechanics and common sense.

Introduction

An important line of research in physics teaching has been concerned with students' conceptions about specific contents. Work of this type, starting in the mid-seventies, demonstrated that individuals develop forms of understanding of physical situations that differ of those presented in scientific theories taught at school. What has been observed are conceptual structures, alternative to the scientific ones, which are highly valued by the students. That characteristic of the so called *alternative conceptions* explains, partly, their resistance to change.

Educators have mapped alternative conceptions in the various fields of physics and of science in general (Pfundt and Duit 1994).

In spite of being framed within the research tradition of alternative conceptions there are some points of difference between this study and the mainstream. Most of the work on alternative conceptions has the purpose of tracing the profile of students' conceptions in the use and understanding of physical concepts, as for instance students' conceptions about the dynamics of movement, about energy, about heat and temperature.
This enables one to evaluate students' interpretations of specific scientific concepts. It has produced guidelines for teaching strategies that should lead to changes in those

interpretations towards the scientifically accepted conceptions. These investigations have produced an understanding of the processes of conceptual construction of physical knowledge by students.

Although basic to the construction of physical knowledge, concepts are not sufficient on their own. Concepts are actually structured into nets on which thought operates. Theories are the scientific expression of those conceptual nets, where each concept links to others producing an integrated whole that is superordinate to its parts.

Having in mind that perspective on scientific theories, research on alternative conceptions can be seen as a way of identifying alternative conceptual structures present in students' understanding. Although, in many occasions, concepts in those structures overlay the scientific versions, their internal organisation is different, resulting in alternative forms of interpretation of natural phenomena.

That approach, however, is only part the issue. Scientific structures are the fruit of historically located constructions. Although in teaching we usually shorten time when focusing on a theoretical structure (like Newtonian mechanics or classical electromagnetism), it is necessary to remember the construction processes that lead to it. Epistemological and historical work have highlighted the importance of *Principles* in the genesis of the physical theories. They function as generic guides for scientific production and, as Einstein (1950) would say, are responsible for the production of theories which have a logical perfection and solid foundations. The investigation on the understanding and use of scientific principles by students can be seen as a way of investigating the processes of construction of conceptual structures for the interpretation of physical situations. The present study is of that type.

Choice of content

Although many principles are part of scientific knowledge, we opted for one that had a major role in the structuring of theory. The Principle of Relativity played such a part in the structuring of the Theory of Special Relativity. Historical studies reveal details of that scientific episode, that has been used as an illustrative exemplar for the links between principles and theoretical structuring.

Historical analyses show that the Principle of Relativity, as presented by Galileo and turned more precisely by Newton, was threatened at the end of the XIX century in the context of optics and electromagnetism. The ether, first optical and later electromagnetic, suggested, against the Principle of Relativity, a privileged frame of reference for the proposal of physical laws. The privileged formulation of Maxwell's equations for an observer resting in relation to the ether seemed to indicate the possibility of determining absolute speeds.

Lorentz's electromagnetic theory, based on the idea of the ether and in the electric and magnetic fields that expressed its state, constituted a promising program. The four laws that described the properties of the ether made it possible to interpret of a large amount of experimental data, suggesting that the physical bases of electromagnetic phenomena were well grounded. That conviction of the power of electromagnetic theory lead the scientific community of the time to extend the electromagnetic perspective to all the branches of physics. (Miller 1981, Buchvald 1988, Paty 1992)

The development of that research program lead to the search for and interpretation of electromagnetic phenomena on moving frames of reference. The research field called "eletrodynamics of moving bodies" met several problems when faced with the need to determine effects that should be produced by movement relative to the ether. Although research in electromagnetism moved forward as a whole, and in particular with the theory of the electron proposed by Lorentz in the end of the century XIX, the part dealing with moving bodies suffered from an incompatibility with some experimental data. Attempts were made to resolve these with the introduction of some auxiliary hypotheses (the contraction of the spaces, local time, etc). Einstein's Special Theory of Relativity was produced in this context, assuming the Principle of Relativity as a guide in the construction of a conceptual structure compatible with it.

In addition to the functional issue, inherent in scientific knowledge itself, it is important to highlight the pedagogic reasons for the choice of the theme. There is a strong interest among the community of physics educators in the introduction of more modern content at basic levels of teaching (Freire Jr., Carvalho Neto, Rocha, Vasconcelos, Socorro, dos Anjos 1995; Villani and Arruda 1998). Our research also seeks to contribute to such efforts.

Our work proposes to investigate the understanding and use of the Principle of Relativity in students' interpretative activity.

Methodology

The research was conducted with a sample of students from the first and last year of the Physics course at Universidade Federal de Santa Catarina, Brazil. All of them had already studied Galilean relativity and changes of inertial reference frames. The graduating students had also studied topics of Special Relativity as part of basic physics (in mechanics and electromagnetism) and in modern physics.

We followed methodological procedures typical of most research into alternative conceptions. Clinical interviews were based on physical situations presented either in drawings or in simple sets with real equipment. We did look for situations where mastery and application of the Principle of Relativity by the subjects could be evaluated. We were inspired by a sequence in Galileo's *Dialogue Concerning the Two Chief World Systems*, where he attempts to convince his Aristotelian opponent about the impossibility of effects of the movement of a ship on several mechanical phenomena in its interior (such as the flight of insects, fall of bodies, etc) being detected. In our adaptation, a very fast modern train was used as a substitute for the ship.

The students were asked to imagine that the room where the interview was taking place was a carriage in that train, which movement would always be kept at constant speed in a straight line, without variation in altitude (that was an important detail because in that case there is no variation of atmospheric pressure). The movement of the train could be, hypothetically, gauged by a digital speedometer placed inside the car, and it could be moved at low and high speeds. Low speed would be of the order of everyday movement, something around 50 km/h. High speed corresponded to values very high in comparison with normal everyday situations; those values varied, ranging from 500 km/h to something close to the speed of light. The important aspect in the setting of high speed was that the situation should be one detached from the interviewee's everyday experience.

The interview protocol always started by presenting the situation of the train at state of rest. It then asked if there would be any change in the situation if the train were moving instead. That movement would be first at low speed and later at high-speed. It is important to stress that the period of acceleration, when the train goes from low to high speed, was not considered during the questioning. The students should state if there was any change or not and then justify their answers. The interviews were audio recorded and transcribed for analysis.

The situations presented in the interviews were related to the subjects of mechanics, heat, electricity, magnetism, optics and sound, and were designed in order to enlarge the physics domains under consideration. Two questions about biological situations in the human body were also included. The list of questions used in the interviews is given below:

Question 1: Pendulum - An object suspended by a string was set to oscillate parallel to the longitudinal direction of the room.

Question 2: Volleyball match - The students were asked to imagine that there was a "sports car" in the train, with a volleyball court placed in the longitudinal direction of the train. They were requested to analyse various phenomena that occur during a game.

Question 3: Boiling temperature - A beaker with boiling water. It was asked questions focusing on the boiling temperature and the time for the water to boil.

Question 4: Balloon - That situation consisted of a balloon full of air, considered as spherical to simplify the analysis. The possible changes discussed were related to the volume and form of the balloon.

Question 5: Level of water - A cubic recipient with water was analysed. Possible changes on the level of the water and on the horizontal form of its surface were points considered in the discussion of the situation.

Question 6: Electric interaction. - In that situation an outline represented two charged repelling spheres, supported by fixed insulated frames on the table, and longitudinally aligned.

Question 7: Compass - A compass and two magnets were arranged in form of a "L", with the compass at the vertex. The discussion was conducted so that the student related the direction of the compass needle with the position of the magnets, considered their polarity and distance.

Question 8: Reflection light - An outline where a light ray was reflected by a plane mirror was presented. The incident ray moved in the longitudinal direction of the room and was reflected in the transverse direction. The questions focused on the relation between the angles of incidence and reflection.

Question 9: Refraction of light - An outline presented the refraction of light by a convergent lens. A beam of white light was incident parallel to the longitudinal direction of the room and converged at the focus of the lens. The students were asked to analyse the phenomenon, in particular the position of the focus.

Question 10: Bell - In this situation an outline represented four persons around a circular table, in the centre of which there was an apparatus that could simultaneously ring and flash. It was asked if there were differences in the reception of the sound and flash and who received the signal first.

Question 11: Arterial Pressure and temperature of the body - That question referred to effects on the human body. Initially the interviewees were asked if any change on a person's arterial pressure was to be expected with the train in movement. The same was asked about the body temperature.

Question 12: Inference – The students were told that the speedometer was not functioning, and asked if they could infer the state of the train (rest, low speed, high speed) by any method internal to it.

Results

Students' answers were initially classified according to their views about the existence or not of changes in the situations presented when the train was in low or high speed. Table 1 shows the affirmative (S) or negative (N) answers in relation to each case, low speed (V <) and high speed (V >).

[Table 1 here]

We classified the students' views into six categories (Table 2), two for those that predicted changes on the phenomena, and four for those who did not.

[Table 2 here]

NEGATIVE ANSWERS CATEGORIES

Although predicting correctly that there would be no changes due to different speeds, the reasons advanced by the students were wrong. They cannot be considered as indicating that those students accepted and applied the Principle of Relativity. In none of the interviews was the Principle explicitly mentioned as a justification for the non-existence of effects caused by the movement of the train on the presented phenomena. The Principle of Inertia and the notion of inertial frame of reference were the ideas most used in the interviews. Although generally valid in mechanical situations, it should be stressed that they were also used in other situations and generated a number of categories. Beyond that improper use of the concept of inertia, alternative interpretations were also made, resulting in the four categories that are discussed next.

1) Export of inertial thought

The concept of inertia was used extensively in the justifications given in the interviews, be it in the form of the principle of the same name or in the definition of frames of reference. From the scientific point of view, it can be demonstrated through the Principle of Inertia that the laws governing mechanical situations or, more specifically, those which can be reduced to a mechanical approach (masses interacting through forces), do not depend on the motion of the frame of reference in which they are, in as far as they are inertial ones. The situations of the pendulum and of the volleyball match (Questions 1 and 2) are emblematic in that sense. Nevertheless, we found a series of students' answers that did not restrict the use of that kind of reasoning to mechanical situations, using it for phenomena involving electricity, magnetism, luminous propagation, etc, where the concept of inertia is scientifically not operative. Those phenomena are outside the strict domain of mechanics and, consequently, the concept of inertia should be not operative there.

That sort of situation appears in the considerations of Juca to the Question 3 (boiling temperature of water). When questioned about the changes on the phenomenon with the train in movement, he answers:

"If the velocity is constant, I think is the same [kind of] behaviour. I think if the system that we have is an inertial frame… it does not change ".

The answer of Eduardo to Question 6 about the electric force follows the same pattern. When questioned about changes in the electric attraction between two charges with the train in movement, he answered:

" No. One continues in a inertial frame. The forces will be of the same sort ".

Table 2 shows the students that used this strategy and the questions that were answered with this form of reasoning. In those answers there is not an articulation between the phenomena under analysis and the fact that the frame is inertial. The students used the argument reasoning as if it was a mechanical situation, where the invariance of its behaviour for any inertial frame is a well-known result and perfectly articulated inside dynamics. What seems to happen in these answers is the transfer of a dynamical equivalence to the situation analysed (electric). It was in that sense that we stated that the terms “Inertial Frame” and “Inertia” are used by the students as “magic words”, because they do not have any specific interpretative function. They express an equivalence of systems in uniform motion with those at rest.

It is interesting to notice that this strategy has similarities with a procedure employed in classrooms. In kinematics, situations such as the overtaking of a vehicle by another can be analysed using different frames of reference, the result being independent of the choice (fixed to either one of the vehicles or to the ground, for instance) and, usually, what is done is to look for the one that makes the analysis easier. As there is an *a priori* equivalence among the various kinematic descriptions, the analysis from a given frame makes it superfluous for any other.

Another aspect related to this misuse of the inertia concept is the existence or not of fictitious forces. For many students, the invariance of the considered phenomena results from the non existence of such forces. Let's consider, for instance, Eduardo's answer to Question 7 about magnetism.

"... the forces acting [in the compass] would be the same ones, independent of the fact of the train being moving or not…If the speed was changing, it could give appearance, by inertia, to those so called imaginary forces. But with constant speed, the only forces that act on the charges are the electric forces and here the magnetic forces. In the same way that they act with the frame in rest ".

The students seem to believe that the only possible effect, due to the movement of the train, on the phenomena is the appearance of fictitious forces. There is here a reduction to purely mechanical interpretations .

2. Group speed

Another strategy used by the students for construing their answers was based on the lack of relative speed among the parts that composed the phenomenon. By considering the fact that all the objects inside the train moved together, the situation was identified with that at rest. It did not seem to matter to the students if the movement of the group would be uniform or not, a posture contrary to inertial physics, and even to Special Relativity. The simple fact that observer and experiment were at relative rest would be considered enough as a criterion for establishing the behaviour of the phenomenon.

For example, Alberto, justifying his negative answer to Question 7 (compass), expressed himself in the following way:

"You would continue being the same system…The whole system moves… the whole system moves with the train ".

José argues in a similar way in Question 1(pendulum) and 3 (boiling water)

"[It doesn't change] because it would be resting in relation to the car."

"I am at rest in relation to the car, it would be sort of zero speed. It would have the same characteristics ".

These answers made it clear that the argument is based on the common speed of all the elements of the system. There was no concern in the answer about if the shared motion was in a straight line and with a constant speed.

In another interview extract, Vinícius tries to express the reasons that made him deny changes in the presented phenomena:

"I am reaching the conclusion that all experiences that we did have the same behaviour. As there would not be any variation of speed I didn't modify my answer…and even with <u>variation of speed</u>, since we are travelling with the total speed, …for all the experiences, I didn't modify my answer…[I] have the following concept: …if you have a speed and there is something with you at that speed, it has to stay in the same speed that you are…"

In this sentence Vinícius expresses a kind of "wide Principle of Inertia ", that would be valid for any type of speed. It would be determinant in the interpretation of any phenomenon, as if he implicitly believes that all the laws of physics depend on the relative motion among the parts of the system.

Maria, another student, justified a negative answer to Question 1 (pendulum) saying that:

"Everything will have the same speed. The speed won't influence only the little ball. It would influence everything ".

In this argument, the element that stands out it is a type of "principle compensation". The influence of the movement of the train would not be felt because it is distributed to the whole. The statement of Maria seems to make evident the basis of this thought style. What warrants the identity of the phenomenon in the moving situation is that there was no unbalance among its parts. If the movement adds something to the phenomenon (for example, a small displacement, an inclination, etc), that happens for the whole of its parts, maintaining a relative balance.

This line of argument seems to have a point in common with that discussed previously about inertia. While, for those students, the fact that the system had a uniform velocity warranted its complete equivalence with the system at rest, here the equivalence is established through the common movement of the parts composing the system. As in the previous case, it is not necessary to analyse the phenomena in the train in movement, but to transpose the results assumed with it at rest, because eventual effects will be present everywhere and they will be mutually compensated.

3. No relation between speed and phenomenon

Another point that was noticed in the analysis was the students' frequent allegation that there would not be any relation between the speed of the train and the focused phenomenon. A lot of answers seemed to express the idea that the question was absurd, as if by denying it there was no need of any justification. In that conception, the movement of the train would not affect the characteristics of the phenomena.

The questions with larger incidence of answers of this type were the non dynamical ones, that is from the third onwards.

Roberto answering Question 6 (electric interaction) and Question 7 (compass), expressed his view by saying:

"I don't see how the speed of the train will alter the nature of the interaction between the electric charges. In the same way, I don't see how the speed it alters the interaction of the magnetic force".

Eduardo answered Question 3 (boiling temperature) in the following way:

"Let's say I can't find any influence of the speed in the boiling point".

Caio justifying its denial in Question 6 (electric interaction) said:

"I can't see the association of the movement with the electric force, they are independent things".

The same student answering to Question 8 (reflection) argues in a similar way:

"Light always moves in straight line. Reflection does not depend on the movement. Reflection depends only on the surface and not on the speed ".

Maria, on the same question, affirmed that:

"The speed of the train have nothing to do with the boiling of the water ".

The common thread to all these answers is that the argument was limited to the denial of the influence of the speed. The students did not attempt to complement that statement with a more analytic evaluation of the situation. For analytic evaluation we mean one based on a physical model built to represent the situation. This posture could reflect two different interpretative structures. It could be a consequence of the existence of the Principle of Relativity in the interpretative structure that, when used on the situation, would make unnecessary more specific analysis. Alternatively, it could reflect the construction of very poor models used to interpret the situations, which do not include an evaluation of the influence of the speed.

Let us consider, for instance, the question about the boiling temperature of the water. A possible model for that phenomenon would be to consider the temperature as a indication of the average degree of agitation of the particles that constitute the liquid. The boiling temperature would be then the degree of agitation that causes water to change its state. It seem to us that such a model can accommodate, "a priori", questioning concerning the influence of the group movement of the system. The conclusion that the average degree of agitation of the particles does not depend on that speed cannot be seem as immediate. It is necessary to construct a model for that.

Thus, even when the interviewer tried to call attention to a possible effect of the movement on the phenomenon, no more reflection on the part of the interviewees was triggered, as it can be shown in the answer of Alberto to question 6 (reflection): when the interviewer did mention the fact that the mirror moved a little during the trajectory of the luminous ray with the train in movement, the students simply said*: "this is not important"*. Our evaluation is that the simple denial of eventual modifications in the presented phenomena was a result of the models used by the students that did not support questioning related to the movement. Their models did not serve as a basis for analysis, so that to deny possible modifications due to the speed of the train in the question made it unfeasible to see the situation in a moving frame of reference as problematic.

Another factor that corroborates this view is based on the fact of some students justified their answers by using mathematical formulas. For instance Marcelo, when answering to Question 6 about electric charges, considered the changes that the speed would bring to the parameters that appear in the formulation of the law of attraction/ repulsion of charges:

> *"I did change nothing by altering the speed of the train. Thinking on the formula, none of the physical quantities were changed ...There is not any alteration of parameters in my equation ".*

It appears as if the students do not notice that those formulas were originally designed for a situation at rest. That is, the model on which they grounded their construction could not countenance speed as variable. In situations where the speed would became a factor, it would be necessary to reformulate the models and, consequently, their associated formulas.

The history of optics and electromagnetism in the XIX century is a good example of physical models being adapted and modified for moving situations. Well known laws (e.g. the refraction and the reflection of light, the magnetic and electric force) were reformulated when it was needed to understand the behaviour of those phenomena in moving systems such as the Earth (Miller 1981). The several versions of Maxwell’s equations for moving frames of reference, elaborated by Lorentz in the decades of 1890 and 1900, were a result of modifications in the original models of electromagnetic theory, in an attempt to incorporate effects of the movement.

Six students’ answers were included in this category. It is possible that others reasoned in the same way, although non explicitly. It is worth noticing that only one of those six was a first year student (Maria, see Table 2). The other ones had longer experience in physics courses, and a reasonable theoretical background that, in principle, should have enabled them to construct more sophisticated models. It does seen proper then, to question the reasons that lead those students to not do so, a point that will be addressed in the conclusion of the paper.

4.Use of analogies

During the interviews we also found the frequent use of analogies by the students when justifying their answers. When denying that a certain phenomenon modified its behaviour when the train moved, the students looked for examples of situations that were invariant. Maria, answering Question 5 about the level of the water, tried to explain her view with an analogy involving an flying airliner. For her, the normal "behaviour" of the recipients with liquid (glasses, bottles, etc) in the airliner would be an indicative that the situation is not different with the system in movement. She said:

“If you were in the airliner and drinking water, I guess [it] would come over you”.

According to her line of argumentation, to admit any kind of change in the behaviour of liquids in a train in movement would be an absurd in face of what she knew about the behaviour of the same liquids in airliners. She made use of several analogies to deny eventual changes in the analysed phenomena.

Leonora was more incisive and justified the equivalence among the two sides of the volleyball court, using an analogy with situations that we experience on Earth, to show that the question was absurd:

"The Earth is rotating, in the case of the volleyball match would it make any sense to change side if I calculated that the Earth rotates of East for West or of West for East "?

To answer to the same question, Juca made use of an analogy with movements possible to be undertaken on a vehicle in movement. According to his argumentation, there is nothing new in the way we move inside a bus in uniform motion:

"If you were in a bus in straight line, you can stand up, loose the arm and nothing happens. You can play a ball forward and back… You can walk in the bus ".

This answering strategy was widely used by the students. Nine students explicitly employed analogies in their answers, Maria being the one who did it most (in five answers). They selected situations that were familiar their in everyday life one and by *functional comparison* transferred their behaviour of the analysed situations. In this way, many supplied correct answers to the questions.

Part of the interview, however, was directed to situations that transcended everyday life. When the train moved at high speed the objective was to place the question in a context unfamiliar to the interviewee, and to verify how she/he would reason. The procedure was designed to make it difficult to use direct analogies.

Many students were unable to articulate creative answers in this context. They simply ratified their previous answers (at low speeds) stating that no quality modification was being introduced to the situation. This posture can be interpreted as an attempt of extrapolating the daily domain, although without any argument of theoretical order. Basically the student made use of a personal intuition. The use of analogies, in this sense, seems a good cognitive strategy for the interpretation of the immediate real, but inefficient when there is a need to extrapolate, to predict on domains outside everyday experience.

B. POSITIVE ANSWERS CATEGORIES

Some students predicted modifications in the presented phenomena when in a train in movement. That type of answer was based in two forms of reasoning: one already very known and quite explored in the literature, the non inertial pattern of thought (MacDermott 1983; Gilbert and Zylbersztajn 1985), and another showing a superficial knowledge of the Special Theory of Relativity, leading to a form of reasoning alternative to the scientific one.

5. Non inertial reasoning

About one third of the students presented this answering pattern in Questions 1,2,3, and 4, which were about mechanics, and therefore more prone to it. Actually, the absence or misapplication of the concept of inertia generated wrong answers in many situations. Even situations overemphasised in pre-university schooling, such as the release of objects from a moving vehicle (the volleyball match in Question 2), lead to positive answers, due to the absence of a firm grasp of the concept of inertia. That type of reasoning pattern was the object of a research with French university students (Saltiel 1981). The novelty in the current results is that the non inertial pattern was, on several occasions, also exported to other phenomena such as the interaction of magnets and compasses (Question 7) and the propagation of light (Questions 8 and 9).

6. Relativistic Noise

The categories of previous answers were not, in any way, related to knowledge linked to the Theory of the Relativity. However, a group of students did use such knowledge when elaborating their answers, although in a different way from the scientifically accepted one. They showed themselves to have only a superficial knowledge of that theory and, when incorporating some of its concepts in their interpretative structure, they were lead to conclusions contrary of those predicted by it. For this reason we coined the name *Relativistic Noise* for that category, in order to express a perturbation of the pre-existent interpretative structure.

José's interview is typical of that group. When being questioned about the behaviour of the phenomena with the train in low speed, he categorically denied the existence of any change. Even so, when entering in the domain of high speeds his answers were influenced by his interpretations of effects associated with the Theory of Relativity, as the dilation of the time, the contraction of the space, etc. When putting into action what he had “heard” about the Theory, he was in doubt and, in the end, admitted that, perhaps, there were changes. The interview was marked by a confront between his classical conceptions and those relativistic effects. This showed first in the answer to Question 4, when he was asked what would happen with the balloon:

"I never thought of that…, in a speed of 5000 km/h! We are in an airliner with 1000 km/h and it doesn't change [anything]. Now [if it approaches] the speed of the light it’s sort of a complicated thing… Well, I’ve already heard things about the speed of light… of mass increase, changes of time…"

The student admits that when approaching high speed a new, stranger, domain is reached. From that moment his trust in his personal conception diminishes. From the new domain he has some information that, however, are not configured as a structured conception. This information is not articulated with the previous interpretative structure, generating an oscillation between two different positions. One based on his personal conception, that indicates the invariance of the phenomena; other centred on the relativistic effects that he believes to exist in high speeds. The confront is between his criteria and the new information. That point is clear in the following statement:

"I do I first think on what would happen if the speed high? But I don't also see [as it would change]. Einstein said, sort of that the mass is increasing, it has to do with time… I don't understand that. Intuitively it is difficult to enter in my head ".

The scant knowledge of Relativity possessed by the student interfered with his interpretation, and his superficial knowledge constituted a noise, so we suggest the expression *Relativistic Noise* to name this interference. The extracts presented show that these fragmented information prevented his personal opinion about the phenomenon from prevailing. He referred to his personal criterion as "intuition", and made it clear that knowledge derived from the Theory of the Relativity cannot be adequately matched with his views.

Thus, in his own interpretation, he would not see reasons for changes in the phenomenon in the high speed situation. On the other hand, the Theory of Relativity seems to indicate the opposite, for the strange domain of high speeds, weakening his confidence in his intuition, that can be understood as his interpretative structure in action. The following extract illustrates our interpretation:

"I would only change my thought, [because] I don't know what will happen near to the speed of light. Since Einstein spoke about those things… there is the story of the bloke that travels at the speed of the light and finds his brother older."

Trying to assert if the knowledge about Relativity was the reason for the change on answering pattern, the interviewer asked:

"If you had not heard about Einstein, how would you answer the questions?"

The answer was categorical:

"If I had not heard [of Einstein and of the Theory of the Relativity], I would say that [there would be] no [changes]."

Further on in the interview, the confrontation between his construction patterns and his views about Einstein's theory appeared again:

"…intuitively I would say not, but there are the ideas of Einstein… not that I don't believe them. I even believe… the man is highly respected…, but it is a difficult thing to swallow ."

What really motivated José's positive answers was the value he attributed to Einstein's scientific authority, that seems to bring him information from an inaccessible domain. He also pointed out, in different moments of the interview, against his intuition, that "things" exist in the phenomena that should change when the train moves. Table 2 presents his positive answers only for the high speed cases. It is observed that not all the phenomena would be modified for high speeds. In spite of believing that relativistic effects always appear in high speeds, there are situations where he believes that those effects would not result on perceptible changes.

In spite of believing that relativistic effects would result in changes in the behaviour of the phenomena, he was not able to be precise about the nature of those changes, stating that did not know how the theory operates. Actually, his knowledge about Relativity does not offer an operative base for reasoning. It just indicates that strange things (such as dilation of the time, increase of mass, etc) happen in high speeds.

The interference of the relativistic noise was also felt in interviews with other students (see Table 2). The changes on the so called observables that the Theory of Relativity proposes for observers in relative motion are incorporated for those students, becoming effects which could be detected in high speed situations.

The influence of the relativistic noise in the answers of several students draw attention to the way in which learned content can become part of the students' interpretative structures. In our case, the students had contact with Relativity in courses and, quite probably, in magazines directed to the lay public. The presence of relativistic noise in their answers seems to indicate that they did not incorporate the criteria that make that content operative. In other words, they learned that times dilates, that mass increases, and that space contracts, but they do not know how to use that knowledge. They operate with that form knowledge in a different way from that established by the theory. They incorporated conceptual elements, but not the context in which they are articulated and from which they are given sense, becoming therefore operative.

To give sense to those concepts, the students incorporate them to their personal context, reaching different results from those indicated by the theory. We have then the construction of an alternative conception about a scientific conception.

Every theoretical structure is linked to a problematic context from which it originates. The answer profile just discussed highlights the importance of the context, that enables a theory to supply an interpretation of reality, for the learning of physical content. Out of that context, the theoretical structure is non operative. It would be as a key without a lock. It will not unveil any new world hidden behind a door, but just force other locks that are not its complement.

Conclusions

The most surprising result in this study was the lack of explicit mention of the Principle of Relativity in the students' answers. It was not possible to detect in any of them relativistic arguments for explaining the non-existence of change in the presented phenomena.

In many cases the students denied the existence of change when the train was in motion. What emerged from the analysis is that, for them, the presented situations did not constitute problems to their more immediate knowledge, basically composed of classical mechanics and common sense. Although many students could have made use of content derived from Relativity, since they had had specific teaching, the questions were answered through simpler conceptual schemes. The fact that the Principle of Relativity was not advanced as an argument to deny change in the phenomena can be explained by considering that the situations were not seem as problematic.

Some authors, such as Bachelard (1938), emphasised the importance of the detection of problems in the use of theoretical structures. Due to cognitive economy, a new theory is not used if the old allows for the interpretation of the situation. What can be inferred from that analysis it is that “problematic situation” and “new theoretical structure” compose an inseparable couple.

In our study, the lack of awareness that a situation is problematic in relation to classical physics, that we could define as a relativistic problem-situation, did not lead to the use of the conceptual schemes of Relativity.

This association of problem and theory allowed for the interpretation of another result obtained in the study. For many students the effects of time dilation, space contraction and mass increase, expressed reality in the high speeds cases. For them, those effects expressed facets of the reality transmitted by popular science magazines, course subjects, etc. The incorporation of those conceptual elements, however, was detached from the problematic context that generated them. That situation resulted in the making of personal problematic contexts that could accommodate the relativistic concepts. The appearance of the relativistic noise, detected in the students' answers, can be understood as one of those personal problematic contexts.

In this way, the detachment from the original problematic context of the Special Theory of Relativity generated two different procedures: one that dispensed with its content, because there was not an anchoring context for it; another that created alternative problematic contexts to give meaning to the incorporated content. The absence of the

Principle of Relativity in the students' answers can be seen as a consequence of the first procedure and the relativistic noise of second.

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Table 1. Positive (S) and negative (N) answers for low (<) and high (>) speeds

Name/Question	1 <	1 >	2 <	2 >	3 <	3 >	4 <	4 >	5 <	5 >	6 <	6 >	7 <	7 >	8 <	8 >	9 <	9 >	10a <	10a >	10b <	10b >	11a <	11a >	11b <	11b >	12	total
Ricardo	S	S	S	S	N	N	N	N	S	S	N	N	S	S	N	N	N	N	S	S	N	N	S	S	N	N	S	12
Vinícius	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	0
João	N	S	N	S	N	S	N	S	N	S	N	N	N	N	N	N	N	N	N	N	N	N	N	S	N	N	S	6
Maria	N	N	S	S	N	N	N	N	N	N	N	N	N	N	N	N	N	S	S	S			N	S	N	N	S	6
José	N	N	N	N	N	N	N	S	N	S	N	S	N	S	N	S	N	N	N	S	N	S	N	S	N	N	N	8
Pedro	N	S	S	S	N	S	N	S	N	S	S	S	N	S	N	S	N	S	N	N	N	N	S	S	N	N	S	13
Dora	N	S	S	S	N	N	N	N	N	N	N	N	S	S	N	N	N	N	N	N	N	N	N	S	N	N	N	6
Paulo	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N					N	N				0
Miguel	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	N	N	S	N	S	N	S	N	S	N	S	S	12
Juliana	N	N	N	N	N	N	N	N	N	N	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	S	8
Leonora	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	0
Juca	N	N	N	N	N	N	N	N	N	N	N	N	S	S	N	N	N	N	N	N			N	N	N	N	N	2
Alberto	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	0
Roberto	N	N	N	S	N	S	N	S	S	S	N	N	N	N	N	N	N	N	S	S	N	N	N	N	S	S	S	9
Clóvis	N	N	S	S	N	N	N	N	N	N	N	N	N	N	N	N	S	S	S	S	S	S	N	N	N	N	S	8
Caio	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	0
Alice	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	0
Eduardo	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	0
Marcelo	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	0
Natália	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	0
Lucas	N	N	N	N	N	N	N	N	N	N	S	S	S	S	S	S	S	S	S	S	N	N					S	10
Sum of S	1	5	5	8	0	4	0	5	2	6	2	5	4	8	1	4	2	6	1	4	5	8	2	8	1	3		100 S
Total of S for question	6		13		4		5		8		7		12		5		8		5		13		10		4			

Table 2. Students' strategies

Name/Strategy	1) export of inertial thougth	2) group speed	3) no relation between speed and phenomenom	4) use of analogies	5) non inertial reasoning	6) relativistic noise
Ricardo *					q1, q2	
Vinicius *		q1		q1		
João *						
Maria *		q1	q3, q6	q5, q7, q9, q10, q11	q2	
José *		q1, q3, q10		q2, q4, q11		q4, q5, q6
Pedro *					q2	q1, q2, q3, q4, q5, q7, q8, q9.
Dora **					q2	
Paulo **	q 7	q1, q3		q2		
Miguel **						all questions
Juliana **	q8					q1, q6, q7, q8, q11
Leonora **			q3	q4		
Juca **	q3			q2		q8, q9
Alberto**		q6, q7, q8, q9, q10	q3, q4, q5, q11a	q2		
Roberto **			q6, q7 q8, q11a		q2	
Clóvis **	q5, q6			q11	q2	q8, q9
Caio **	q1, q4		q3, q6, q8	q2, q5, q10		q7
Alice **						
Eduardo **	q6, q7		q3, q4			
Marcelo **	q9	q8				
Natália **	all questions					
Lucas **						q6, q7, q8, q9

* First Year Students ** Final Year Students

q1-question 1; q2 -question 2, ...e t c