HISTORY AND PHILOSOPHY OF PHYSICS AS TOOLS FOR PRESERVICE TEACHER EDUCATION

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Introduction

Since 1999 a model of "teacher-as-researcher" has been implemented within the Post-graduate School for Secondary School Teachers (SSIS) at Bologna University, Physics-Computer Science-Maths branch (Grimellini Tomasini, Levrini, 2003). In this context teaching materials have been produced and used in order to drive student-teachers (STs) from a teaching model based on a pre-fixed syllabus (that is a *list* of contents to be completely covered and presented to the students) to a model based on a teaching project (that is a *conceptual path* to be designed by the STs in the light of XXth century culture according to cultural and educational goals, based on a selection of disciplinary concepts and open to epistemological reflections).

The materials concern spacetime Physics (from Classical Mechanics to the basic ideas of General Relativity) and represent the result of a process of educational re-construction, in which subject aspects are integrated with historical-epistemological and cognitive ones (Levrini, 2002a; Levrini 2002b). The materials have been designed on the basis of the following criteria:

- privileging the quality of knowledge rather than the quantity of notions to be transmitted;
- addressing topics and questions of XXth century Physics on the basis of a "modern teaching" of classical Physics;
- fostering an image of Physics as "cultural product" characterised by the co-existence of different interpretations of the same formalism and by the interconnections with other cultural fields;
- fostering the creation of a flexible learning environment where each student is encouraged to find his/her own path and to construct his/her cultural, cognitive and emotional growth.

The paper will focus on a study carried out on the teaching practice period of two STs, scheduled in the forth (and last) semester of SSIS. The study aims at giving a contribution to the debate about the possible roles of history and philosophy of Physics in pre-service teacher education. It will be shown, indeed, how competences in history and philosophy of spacetime allowed STs to interpret and solve cognitive barriers met by secondary students in passing from classical to modern Physics learning.

The contribution of Special Relativity in overcoming "classical" views of space and time: an historical-philosophical open-ended question

Within the courses of History/Epistemology of Physics, Physics Education and Lab of Physics Education (compulsory SSIS courses for certifying Physics teachers), a topic addressed in depth is the contribution given by Relativity to the debate about space and time in Physics. The topic is analysed from different perspectives (historical, philosophical, conceptual and educational) and by the analysis of different texts (original memories, papers from the research in history and philosophy of Physics, papers from research in Physics education and textbooks).

In the analysis some points particularly stressed are:

1. In addressing the contribution of SR in letting absolute space and time fall down, the arguments usually provided by textbooks are the extension of the principle of relativity to electromagnetism and the relativistic effects of length contraction and time dilation. The meanings (implicitly or explicitly) attached to absolute space and time are, then, of "privileged frame of reference" and "invariant space distance and time interval". Nevertheless, Newton's original meaning of absolute space and time was of "substantivalist containers": real entities whose existence is independent of the existence of the matter contained. Few, if any, traces of how SR deals with this meaning can be found in textbooks.
2. The question concerning substantivalist conception of absolute space and time is still open and neither Special nor General Relativity (GR) give a definitive answer. Against substantivalism,

Einstein provided operational arguments supporting the idea that space and time are a set of formal relations among events, constructed by human reason in order to organise or comprehend the factual world (the “relationalist” view). In the first original paper about Special Relativity (SR) (1905), the great attention paid by Einstein in defining space and time through their operational definitions is very evident. Nevertheless, only three years later, Minkowski proposed a geometrical “substantivalist” interpretation, according to which the main contribution given by SR is the unification of the two Newtonian containers in a new absolute entity “spacetime”, as much substantival as Newtonian space and time (Levrini, 2002b).

3. In spite of its ontological implications, Minkowski’s geometry had a great relevance in the development of contemporary Physics but, conversely, only very few teaching proposals take Minkowski’s geometry into serious account. Important exceptions within secondary school texts are Taylor&Wheeler (1992) and Fabri (2001).

In the following it will be shown how STs used the historical-philosophical comparison between Einstein’s and Minkowski’s interpretations for enabling secondary school students to look critically at the Newtonian view of space and time and to overcome some difficulties in understanding basic concepts of SR.

The research context and the problem

The teaching practice period we shall considered is quite uncommon: it concerns an elective course for students attending the last year of a Scientific Lyceum (18-19 years old) who had previously studied relativity along a geometrical path designed by the classroom teacher on the basis of Fabri’s text. Within this context, the aim of the path designed by the STs was addressing historical/epistemological topics related to relativity (among which “space, time and relativity”) in order to provide students with suggestions for an interdisciplinary personal essay that Italian secondary students have to discuss during their final examination. The practice period was covered in 20 afternoon extra-periods and 12 voluntaries students attended constantly the course.

The study concerns the analysis of a classroom work section in which STs had to cope with students’ difficulties arisen from an exercise about proper time (fig.1).

Exercise: You are standing by the tracks of a railway station and a train is passing in front of you with constant velocity; an experimenter on the train sends a light signal from the front of the wagon (point A) to the end (point B). For the experimenter on the train, is the measurement of the time taken by the light from A to B a proper time? Justify your answers.

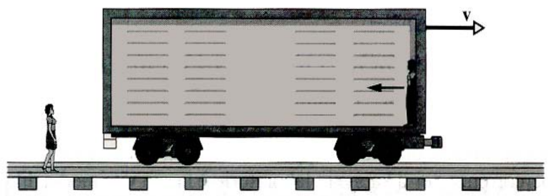


Fig. 1 – The exercise (Halliday et al., 1997)

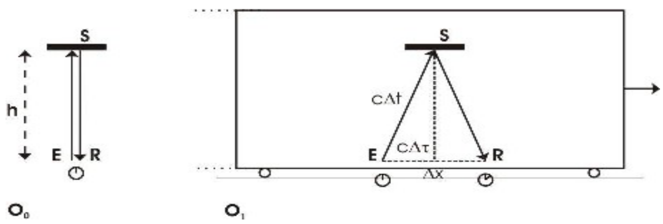
The exercise was submitted to the whole class by the host teacher during one regular morning lesson, in the same period in which, in the afternoon, the STs held their practicum and, in the morning, they observed the class. An important information related to the following discussion is that, when the exercise was submitted, STs had just presented the debate between Einstein and Minkowski in their afternoon classroom activites.

The exercise was chosen by the host teacher as an opportunity for revising some concepts prior to the final examination. The exercise appeared in the textbook quite trivial, being presented immediately after the operational definition of proper time: “*If, with respect to a given frame of reference, two events happen in the same place, the time interval between the two events as measured in that particular frame of reference is called ‘proper time’*” (Halliday et. al., 1997). Out of the operational path, the exercise revealed itself as a trap for most students and the great majority

of them gave the wrong answer: "*the experimenter measures a proper time because he is in the same frame of reference of the light signal".*
Immediately it was clear a "clash" between two different perspectives:

- the algebraic operational perspective from which the exercise was formulated;
- the geometrical formal perspective, within which proper time was introduced as "invariant length" of space-time distance through the "light clock" thought experiment (fig. 2)

From the light clock thought experiment:



to proper time, by applying Pytagoras' theorem:

$$\Delta\tau = \sqrt{\Delta t^2 - \frac{\Delta x^2}{c^2}} = \frac{\Delta t}{\gamma}$$

Fig. 2 – The "geometrical" definition of proper time (see, for example, Fabri, 2001).

The problem provoked unexpected and interesting effects: a firm refusal by the students of the "operational arguments" provided by the teacher but an uncommon involvement in the discussion. On requirement of the host teacher, STs took on the task of going in depth, understanding what was happening and planning a specific intervention to be performed during their afternoon practice period.

How STs dealt with the problem

Given the problematic situation, the discussion spontaneously developed from the exercise was shared within a collaboration among the STs, experienced teachers (the host teacher and a teacher uncharged to supervise practice periods) and ourselves in order to formulate some interpretative hypotheses. As result, we concluded that the discussion seemed to point out difficulties at different levels:

- difficulties in comparing different definitions of the same concept and, more generally, in recognising the peculiarities of different perspectives from which concepts gain significance;
- some common (and well-known) misunderstandings about the meaning of the light clock and the proper time (Posner et al., 1982), strengthened by the geometrical definition of proper time.

Evidences of misunderstandings were provided by sentences like "[proper time] *is that time calculated in the same frame of reference of the object, of the laser ray… that is the event.*" (Marco) or "*a characteristic time of a given phenomenon. […] we have defined proper time as an invariant feature of a determinate object"* (Lorenzo).
The quotations suggested the hypothesis that, beyond the problem of understanding proper time, there were misunderstandings concerning:

- the concept of event (seen as "process", "phenomenon with a time lenght");
- the concept of invariant (seen as "intrinsic property of something", without any connection to transformations among different frames of reference);

Moreover, no role and no meaning were attached to the necessity of localizing the events before evaluating their space-time distance. As Posner and collaborators would say, the postulates of the theory are learned without any deep consideration regarding their counterintuitive implications (Posner at al., 1982).

All these problems prevented students to see a difference between the light clock thought experiment and the exercise situation. In both the situations students saw the same "event" (the propagation of a light ray), with the same "invariant" (intrinsic) properties ("the proper duration") and, consequently, both the observers on the train had to measure a "proper time".
An overall view of misunderstandings lets a general tendency come out: the tendency of shaping every notion in the direction of ascribing proper time all the properties of absolute Newtonian time, i.e. its being more "real" than other time intervals and, mainly, completely separate from space.
On the basis of these hypotheses, the STs planned and developed intervention in order to:

- enable students to look (consciously) at the discussion as an example of a culturally-based comparison among different conceptions of time (Newtonian vs. relativistic one) and not as a contingent exchange of ideas aimed at overcoming a local cognitive barrier;
- enforce the passage toward a relativistic view of space and time, by stressing the role of 'c' invariance in interweaving space-and-time and by analysing the interweaving from different perspectives (both operational and geometrical);
- re-conceptualise proper time and proper length as very special cases of spacetime intervals in which space and time can be still taken apart.

The interactive intervention, performed by one ST, was articulated along three phases:

- Analysis of the exercise in the light of Einstein's operational perspective;
- Analysis of Fabri's formal path in the light of Minkowski's substantivalist perspective;
- Coming back to the exercise and comparing of the different perspectives.

The intervention, as well as every lesson of the teaching practice period, was audio-recorded and transcribed. Moreover, at the end of the course a task was submitted and it included questions about proper time.

First results and implications

The final task indicates the success of the intervention: 10 out of 12 students provided satisfying answers concerning proper time, by showing to be able to cope with both the operational definition and the geometrical "invariance" property. In particular, an analysis of the transcript highlights the relevance of going to the roots of the problem, in order to re-construct a deep coherence between the operational and the geometrical definition of proper time. The lesson was mainly successful in providing students with conceptual tools for:

- understanding the connection between the postulate and the need of looking at space and time as two intrinsically interwoven quantities;
- getting used to different languages by which the space-time interweaving can be expressed (the "Einsteinian" operative construction of the latticework of rods and clocks *vs.* the "Minkowskian" geometrical formulation of spacetime);
- situating the definitions within different epistemological positions.

As consequence of these passages the difference between the light-clock thought experiment and the exercise situation became for the students relevant and, finally, obvious.
The intervention finished with an interesting example of students' involvement in the game of moving among different perspectives:
ST. *then [coming back to the exercise…] in your opinion, what would Einstein have answered? How much is proper time?*
All (chorus)*: it does not exist! It cannot be measured!*
ST. *and Minkowski?*
Luca*: Zero! He would have taken the mathematical concept as the starting point for his deductions… as foundation…*
From our perspective, the described experience strongly supports the need of providing prospective teachers with historical/philosophical competences. In this case, indeed, such competences represented for STs a source of cultural and professional tools for:

- solving a problematic classroom situation;
- situating the conceptual difficulties within a cultural frame;

- fostering the creation of a teaching/learning environment where students felt personally involved. As some of them comment:
  "The debate between substantivalism-relationalism gave us the hint for discussing of physics also out of school timetable" (Ada), or *"[The comparison] opens the mind, so as that a person has not a strict and limited view of what surrounds him/her. Moreover, having at one's own disposal different interpretations help all of us to form his own view, without accepting passively just one"* (Roberta).

On the basis of the obtained results, we improved the materials and implemented them in four different classes of Lyceum. The materials give great relevance to the historical/philosophical debate between Einstein and Minkowski in order to introduce the geometrical perspective only in a strict comparison with the operational one. This choice is due to the purpose of exploiting the geometrical perspective without offering students formal short circuits between Newton and Minkowski, that could hidden the passage from classical to relativistic Physics. At the moment we are analysing the data and re-organising the material in a web-site both for pre-service and in-service teacher education, within the Italian National Project FFC, coordinated by P. Guidoni.

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