A DIALOGICAL AND CONVINCING APPROACH FOR TEACHING GALILEAN RELATIVITY OF MOTION: TRANSPARENCIES, VIDEO AND MULTIMEDIA RESOURCES

Marina Castells; Aikaterini Konstantinidou; Josep M. Cerveró & Modesto Cabellos, *University of Barcelona, GRIEC.* marina.castells@ub.edu

Abstract
This paper presents an approach, specific activities and multimedia resources for teaching-learning the topic of Galilean Relativity of motion. The approach is mainly inspired by Galileo Galilei's *Dialogues,* but also takes into account the results of research into students' scientific conceptions of this topic, our experience in teaching it and a dialogical perspective on teaching and learning, which considers that the construction of scientific knowledge must come from students' conceptions and arguments. The approach and activities have been applied to Primary Teacher Training, but could be useful in other educational levels.

1. Background and proposal
In the context of science education today, we consider that students arrive at school with background knowledge that is undoubtedly valid and powerful enough for them to interpret the surrounding world. From research on students' scientific conceptions, we know that part of this knowledge conflicts with scientific knowledge. In addition, some students are reluctant to reconsider what they think they know. As Millar (1989) and Osborne (1998) stated, teachers have to persuade pupils of the value of this new way of seeing the world. To quote Ogborn (1996), teachers have to create a need for knowledge in the pupils (creating differences) that prepares them for the new knowledge so that they will come to accept it. We agree that teaching must come from students' ideas and conceptions and from their own way of arguing. However, as students cannot discover a scientific way of seeing the world on their own, we must bring it to them. In other words, we must present this new way of looking at the world to them (Guidoni, 1990).
When learning involves many changes in pupils' knowledge (Leach and Scott, 1995; Ogborn, 1996), such changes should be guided. Key episodes in the development of science, such as the *Dialogues on the Great World Systems* by Galileo, can provide useful teaching tools and approaches.
This paper presents an approach, specific activities and multimodal resources for teaching-learning the topic of Galilean relativity of motion. The approach was mainly inspired by Galileo's *Dialogues*. However, it also takes into account the results of research on students' scientific conceptions of this topic, and our teaching experience.

2. Students' difficulties in comprehending Galilean relativity
From a previous study of students' comprehension of Galilean relativity (Castells, 1997) and other research on students' ideas and reasoning related to this topic (Saltiel, 1980; Ramadas et al., 1996), we identified the main difficulties students have in relation to relativity of motion. Some of these difficulties are summarised below:
- Students do not think that the ground and objects that are fixed to the ground can move. They consider that possible motions are apparent, rather than real, motions.
- To describe a motion, students use objects that determine frames of reference, but they do this without an awareness of the frame, and often mix several frames in their reasoning. The ground is the most common frame of reference. It is the natural frame of reference in many situations.

Sometimes, other frames of reference can be used (e.g. a train, ship, conveyor belt, walking man, etc.) because the motion happens inside, on, or in front of these objects.

- Students easily appreciate that when a body is carried by a carrying body that moves (in relation to the ground) it has the same motion as this carrying body (it participates in this motion). However, when this body loses physical contact with the carrying body (or is outside its borders), it loses the shared motion (velocity).
- Students find it difficult to accept that two different references can be used to describe one motion. Situations that involve dragging provide an opportunity to distinguish between different velocities in relation to different frames of reference with relative motion. However, students reason in terms of composition of motion rather than relativity of velocity.
- Students find it difficult to accept that different trajectories (i.e. rectilinear and parabolic) “seen” from two different reference frames correspond to the same motion, and can take the same time to run between the same places.
- Students often confuse the distance run by an object, with the distance between two objects (in motion), as measured in a specific instant of time or using an instantaneous distance.

If we take these difficulties into consideration, we can design a teaching approach that involves several activities.

First, we selected the following kinds of excerpts from the Dialogues: excerpts related to students’ difficulties in learning; those in which the ‘problem of physics’ under consideration is interesting; those in which the ‘common sense reasoning’ could be shared by our students and the general public; and those in which ‘interesting argumentation’ is used to defend the ‘new idea’, which could be used by the teacher to convince students of the scientific ideas. On the basis of the selected fragments, we devised some activities that included different **multimodal resources**.

3. Approaches, activities and resources

3.1. Approaches to constructing scientific conceptions of the relativity of motion and the frame of reference.

In teaching the relativity of motion, we know that *motion as a change of position with respect to a Frame of Reference (FR)* and the *concept of FR* itself are fundamental notions. However, research and our experience as teachers indicate that the FR concept is very abstract and difficult for students to understand, especially in compulsory primary and secondary education. Therefore, we introduced an approach to this concept that is based on Bruno and Galileo’s notion of a *mechanical system* (*MS*) (Tonnelat, 1973), which is more concrete and thus more accessible to our students.

In *La Cena della Ceneri* (1584), Giordano Bruno presents this notion of MS as an ensemble of animate bodies with the same motion in relation to the same reference. A characteristic of this MS is that it is impossible to recognize its motion from the experiments performed inside it.

In this approach, we first introduce *motion as a change of position with respect to a specific object*. Subsequently, we introduce the notion of MS, which is a concretion of an abstract FR, to construct the main ideas about Galilean relativity of motion.

With Primary Teacher Training Students (this could also be done at secondary level), we completed the FR notion of Galileo with that of Einstein and used some texts that clearly illustrate the notion of FR in physics (Jammer, 1970; Einstein, 1970). This notion considers *Object-Space* as a space that is linked to an object of reference, is constituted of infinite points that go out from the object in all directions, is unlimited and moves with the object of reference. Descriptions of motion should also consider time, and we can imagine this space with a clock at every point. This notion of FR is more abstract than Galileo’s, but helps to clarify some problems of relativity of motion. Einstein’s notion of *Event* (an event is something that happens in a particular point of a space at a particular instant of time) is also related to this concept and used in our teaching proposal.

3.2. Activities and multimodal resources for teaching relativity of motion

1. We gave students initial written qualitative problems to explore their conceptions:

> Imagine that you are floating with a tyre in the middle of a river and not swimming. Some metres up-river there is a floating box of wood and some metres down-river there is another box.
>
> a) If you are floating without swimming, will the distance between you and each box change with time? Why?
>
> b) Imagine that the tyre goes flat. Which of the two boxes could you reach first? Why?

Students solve this problem individually and then discuss it in small groups. Subsequently, as a class, we examine the solutions the students have given and their arguments. In relation to the second part of the question in particular, students give several solutions, but their arguments are frequently based on intuition alone. Teachers can then illustrate the "correct" solution using **transparencies**.

This **resource** consists of drawing a transparency for each possible FR. In Part a) of this example, we draw one transparency for the FR that is defined by the land and another for the FR determined by the river water. In general, the transparencies are created by identifying objects that do not move relative to the others and, thus, we constitute an MS (according to the conception by Bruno & Galileo). For example, the transparency FR Land contains the riverbanks and other elements of the landscape; the River or Water FR transparency includes the water, the boxes and the man with the tyre. When one transparency is placed over the others and one or other is moved, one FR can be seen to move relative to the other. Thus, the motion of the objects changes in relation to one or other FR. This activity can be used to introduce the scientific concept of Motion and FR. In fact, transparencies are a cheap and effective resource for constructing the concept of FR from that of MS. This resource helps students to appreciate and accept the scientific solution of the problem, especially Part b), which is more difficult for them. Transparencies can be adapted to any specific situation or problem.

2. A very useful resource for understanding and solving problems on relativity of motion is a **diagram of events**, which is inspired in Einstein's concept of event (position-time).

This resource can be used in the classroom in a *more concrete* or *more abstract* way, depending on the students' level. Here, we present the use of this technique for Part b) of Problem 1 above, in relation to the water's reference frame.

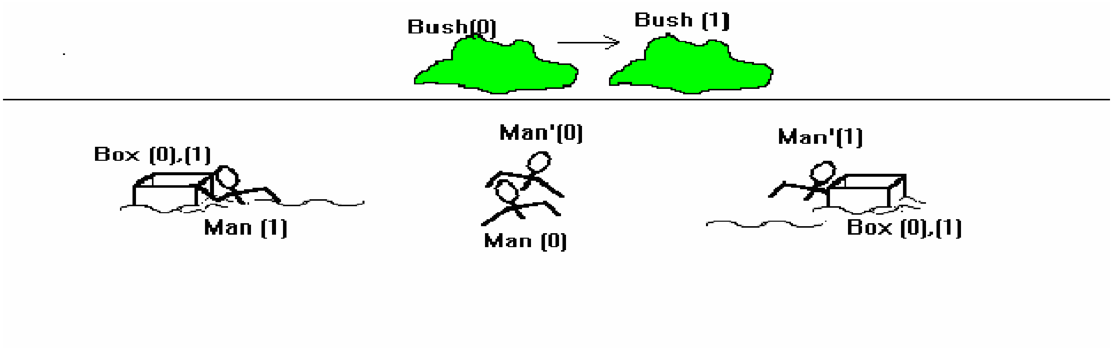


Fig. 2.: Diagram of events relative to the river water

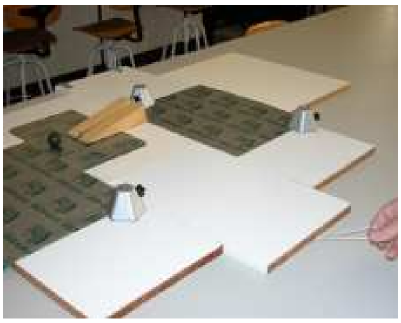
3. We can provide more experiences of "seeing" motion from several FR with the **resource of video**. We have recorded several videos in our laboratory, including one of a man walking in the laboratory who drops a ball or a running train that shoots a ball up vertically.

Fig. 3.1. *Video of a ball falling down "seen" from the FR of the man*

We can ask students questions and discuss how they "see" the motion and why, and then ask what reference they have used. Students consider some FR as natural, such as the ground or the body on which or behind which the motion takes place. They do not consider other possible references in many situations. In our videos, we record a motion that has some specific bodies in the background (laboratory walls, the door, etc.), which makes students "see" the motion in a natural way relative to one or another FR. Thus, we demonstrate that several FR can be used to relate the motions and that the motions change when the FR changes.

Fig.. 3.2. Trajectory of the ball falling from a walking man "seen" from the Laboratory FR

4. Activities that reinforce the concept of the relativity of trajectories to the FR involve the use of **sheets of white and carbon paper**. Another text from Galileo's *Dialogues* that we recommend to our students inspired some experimental activities in which the trajectories provide evidence of motion and, thus, motion relative to the FR. This text is called *The second Day: Sagredo's striking example of the ineffectiveness of motion in common (pp. 171-172)* (Galileo's *Dialogues*).



4.1 Recording trajectories using white and carbon sheets.

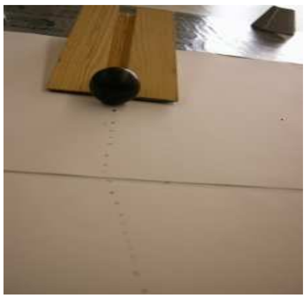
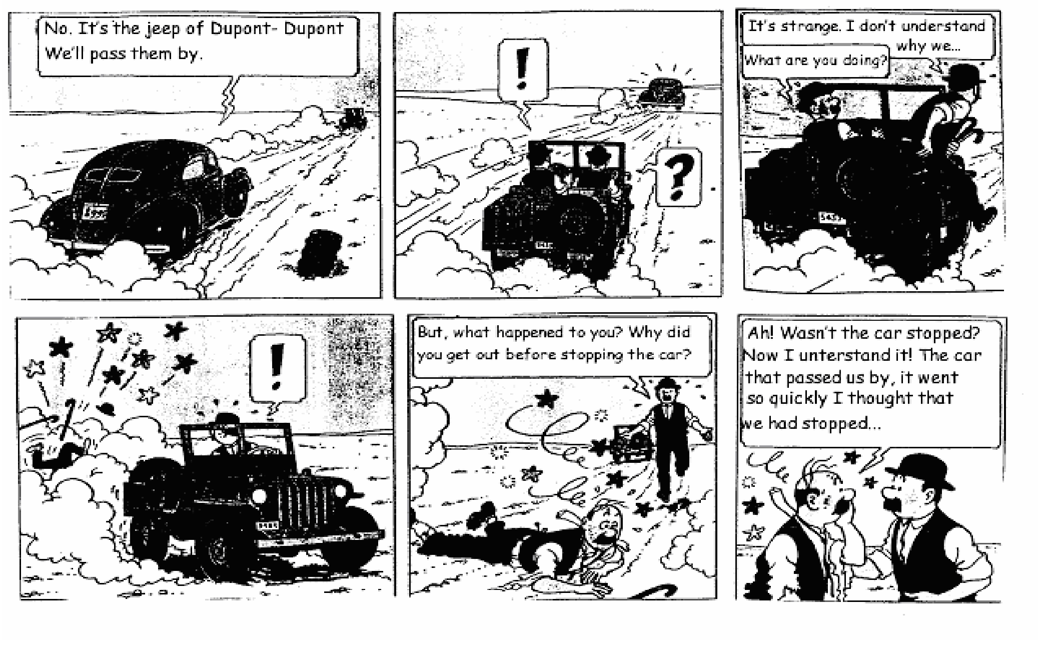


Fig.4.2 The trajectory of the ball relative to the train and relative to the ground

Like Galileo, we use analogies. We ask the students to think of rolling a ball on the suface of a wagon of a train (or on a conveyor belt or any vehicle with uniform motion relative to ground). We ask the following questions in reference to the ball rolling perpendicular to the direction of the train. What is the ball's trajectory with respect to the train? What is the trajectory with respect to the station (the land)? To find the correct answer, we propose an experimental arrangement that is analogous to the aforementioned situation, using sheets of carbon and white paper. We can use two pieces of wood to represent the FR Train and the FR Ground. As we can see in Fig. 4.1, the frame Train (the wood) moves with the sheet of paper, and if the ball rolls off the wood, a trajectory will be marked on the white paper of the FR Train and on the FR Ground (wood at rest relative to the laboratory table), for example. The trajectories marked on the sheets will be analogous to the ball's trajectory in the train FR and in the Ground or station FR. The two trajectories that are obtained help students to change their thinking about motion. We can also use one frame of pasteboard with the sheets (a carbon sheet on top of a white one) that can move over other sheets that are fixed on the laboratory table. With this second arrangement, the two FR are in the same “space” (one on top of the other). Therefore, a more convincing arrangement would be to discuss the motion of a ball into the train as “seen” from the FR Ground, for example.

5. We have also used the **resource of a cartoon** to discuss the relativity of velocities in a quantitative way with students.

Below is a cartoon from one of Tintin’s comics.
Discuss what happens in the story from the perspective of physics.



6. Finally, a new resource is **applet simulation[1].** This type of resource can have an educational function similar to that of the aforementioned resources. However, it is more significant when we use the other aforementioned resources (transparencies, event diagrams, etc.) first. Applet

[1] We used applet simulations of motion from Fu-Kwun Hwang, 2008, Virtual Physics Laboratory (NTNUJAVA), Dept. of Physics, National Taiwan Normal University. The author is a member of the CoLoS (Conceptual Learning of Science) Group: http://colos.org/

simulation has some advantages and disadvantages over other resources. Among others, the simulation of motion can work rapidly with quantitative values and calculations. However, the disadvantage is that it is only useful for the situation for which it has been designed.

4. Discussion and Conclusions

Galileo's *Dialogues* are a very rich source of new approaches for science education. They provide specific ideas for designing problems and other activities related to teaching Galilean relativity of motion in a way that fits in with students' common ways of reasoning. These problems and activities can be adapted using easy and cheap resources, such as simple experiments, texts, transparencies or event diagrams, or new resources, such as video recording or computer simulations. Research shows that this topic is not easy; students have to change their way of viewing the world to a new perspective that goes against common ways of reasoning. This is never easy, and involves more persuasion than discovery. Teachers have an essential role to play in convincing students. New multimedia resources can be useful, but without adequate orientation and support from the teacher, it would be quite impossible to convince students to accept the new ideas.

References

Arcá, M., Guidoni, P. and Mazzoli, P. (1990): Enseñar ciencia, Paidós educador/Rosa Sensat, Barcelona.

Castells, M.,(1997): *Patrons de comportament dels estudiants en resoldre problemes de relativitat galileana, i factors que els influeixen en les respostes i en els raonaments*. PhD., Servei de Publicacions, UAB, Bellaterra, Barcelona

Galileo Galilei (1632): Dialogo di Galileo Galilei Linceo sopra i due Massimi Sistemi del Mondo Tolemaico e Copernicano, English translation (1966) Dialogue Concerning the two Chief World Systems, with a foreword by Einstein, A., USA

Jammer, M.: "Concepts of Space. The History of Theories of Space in Physics". Foreword by Albert Einstein, Harvard University Press, Cambridge, Massachusetts, Second Edition, 1970

Leach, J. and Scott, P. (1995): The demands of learning science concepts: Issues of theory and practice. School Science Review, 76 (277), 47-51

Millar, R. (1989): Bending The Evidence: The Relationship between Theory and Experiment in Science Education. At: Doing Science. Images of Science in Science Education. Ed Falmer Press Chap 2, 38-61

Ogborn et al. (1996): Explaining Science in the classroom. Open University Press, Buckingham.

Osborne, J. (1998): Science Education Without a Laboratory? A Practical work in School Science. Which way now? Edited by Jerry Wellington, London and N.Y., Routledge, Chapter 9 (pp 156-157)

Ramadas et al. (1996): Alternative conceptions in Galilean Relativity; distance, time, energy and laws. In: International Journal of Science education 18 (4), 463-477

Saltiel, E., Malgrange, J.L. (1980): Spontaneous' ways of reasoning in elementary kinematics, Eur. Jour. Physics 1, pp 73-80

Tonnelat, M.A. (1974) Histoire du Principe du Relativity, Paris: Flammarion