History of Science as Context in Physics Teaching Sequences. Levels, Illustration and Framework

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Abstract

The History of Science has been present in the Teaching Sequences in various ways since the beginning of teaching science in schools. Nowadays experts on Science Education recommend the contextualization of the Teaching Sequences and/or activities in order to have meaning and interest for the students. Our framework tries to relate the scholar Science Modelling perspective with the reflections about the Teaching Sequences contextualization. We will comment about possible uses of History of Science as context in the science teaching in the XXI century, and about the levels of context that may be introduced in science teaching based on context or teaching-in-context. A Teaching Sequence and some activities based on History of Galilean Relativity will illustrated our perspective and will be justified through our theoretical framework.

Keywords: History of Science; Secondary Education; Teacher Training; Learning in Context

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Introduction to the problem

Nowadays experts on Science Education recommend the contextualization of the teaching sequences and/or activities in order they have meaning and interest for the students. Teaching science in context is not new in science education but it takes new sense when the aim of the teaching science is related to development of competences, among other the scientific and technological and, as well of many transversal ones in the future citizens. In fact, there is agreement that students have to finish school being able to understand scientific facts and theoretical models, in order to become a critical person to face issues and questions related to science and to scientific information from the media; but not only this, they would share values related to science and technology that make them became citizens able to act with arguments in front of some social problems. The consideration of contexts nowadays is also related to the new curriculum based on the development of competencies, development that has begun with the PISA evaluation of the students' competencies after the compulsory school (PISA 2015).

The context-based approaches, currently considered as an important development in curriculum design, claim to address five major problems in science and mathematics education: first, there is widespread curriculum overload; second, the content of the curriculum is so fragmented that there is incoherence in the conceptualisations attained by students; third, students often cannot transfer knowledge to new situations, fourth, the knowledge taught is too often not relevant to students' everyday lives; fifth, there is confusion about the reasons why science should be learned by students, according to Gilbert (2006). Nowadays many experts consider that context-based curriculum in science education may be an outstanding element to prepare students to overcome this *transference* difficulty, as well some of other identified problems in the students' learning (Finkelstein, 2005; Gilbert et al., 2011; Marchan, 2015; Sanmartí & Marchan, 2015).

What is the conception of context in a teaching-in-context approach?

The concept of context widely accepted in science education is near to the context discussed by Gilbert (2006) when he particularized to specific contexts for the Chemistry teaching based-in-context. This concept of context (based on Duranti & Goodwin, 1992) considers that a context for educational purposes is "a focal event embedded in its cultural setting". In our research group (LIEC-UAB) we adapted the conception of context like:

"a situation or complex problem, socially relevant, and from the student environment (physics or cultural), that is studied during a period of time. From its study the key knowledge necessary to understand this situation or problem will be built, and so, it will help students being able to formulate key questions about the situation or problem and to build, together with the teacher, the new languages and science models for the understanding of the situation or problem and to formulate specific questions related to the context, or to take decisions or actions in relation to questions or problems formulated".

(Marquez, Sanmartí and Izquierdo, 2013; 61-70)

What is true is that the use of a context in science classes needs the interrelation between experimental or experiential facts, languages and ways of thinking in order to construct the science theoretical models. The emotional aspects in a teaching-in-context, as well as personal or social ethical values and moral or religiousness beliefs also interact in the process of learning scientific knowledge with meaning and interest of the students. Understanding context in this wide meaning will imply that learning-science-in context or context-based science means not only learning scientific knowledge using some contexts to do the scientific knowledge engaging to the students, but also means to give meaning to the Learning Activities or Teaching Sequence.

Coming from these context conceptions, we consider a context as a set of five essential elements that give sense to the science scholar activity: a *situation* relevant to students and to society and which favourites a community of practice; the *activity* that has to be interesting for students, constructive of knowledge, linked to inquiry and problem solving processes, and with the shared participation of students; a use and development of *representation external systems* (language, visual representations, like graphs, drawings, gestures, ...), and *internal* (thinking or reasoning); the *re-situation* or *re-contextualization* to other situations or new contexts (the *transference* process). The development of these elements addressed to the construction of the necessary abstract scientific knowledge needs to be done through carrying out activities and the practice of *Metacognition* (Efklides, 2009).

From the literature and our seminaries (LICEC-UAB) (from 2014 to 2016) we stated the main *criteria to identify a good context* to teach/learn Science in a scholar specific context:

a) S*ocially relevant* and that may be *engaging for the students*. Students may ask themselves new questions about the situation/problem and they will be interested to know more about the situation/problem based on the science key ideas and models.

b) It facilitates the *building of scientific key ideas and models* related to a particular matter (Physics, Chemistry, Electricity, …) and its interrelations, as well as their formal or *abstract languages* or *representation systems.*

c) It will increase the opportunity of *transference* by students to the understanding of *other contexts*, as well as to valuation of *new situations or problems* that require students *to take decisions about or to solve them*.

The teaching of science in Teaching Sequences Based-in/on-Context

About the general agreement to the approach of teaching-in-context or based-on-context, there are some important questions: How to choose a context? How to teach-in-context? Are the science education teaching-in-context strategies very different from the ones used when the focus of the teaching is mainly conceptual? Why some particular contexts will favour knowledge transference to new contexts and others not? Nowadays there is no general agreement in the community of experts on the answers to these and other related questions. Looking for in the literature examples of TS Based-in/on-Context of nowadays, we arrive to the conclusion that to know how to use contexts in a TS needs theoretical and pragmatic instruments, but not only this, there is necessary to study and reflect about the experiences made in different scholar contexts and levels of science education.

The instruments

The Contexts in the Modelling Cycle

A *Model of Learning Cycle* (Jorba & Sanmartí, 1997) was built by experts of Science Education to describe the science learning into the Constructivist Paradigm. More recently, this Learning Cycle has been adapted to the perspective of the construction of scientific models or *Science Modelling Cycle* in science classes, taking also in consideration other proposed schemes of the modelling process in a form of a new Science Modelling Cycle (Couso & Garrido, 2016), in which several steps may be differenciated (see figure 2): 1)*Have the need* of the model, 2)*Express/Use of an initial model*, 3)*Evaluate* the initial model, 4)*Review* of the initial model, 5)*Consensuate* a new model, and 6)*Use* the *new model* to explain a *new phenomena* (Couso & Garrido, 2016).

We agree that the Modelling Cycle process refers to the *students learning process* with the orientation and the help of the teachers (*instruction process*) in order that in the first steps of the modelling the link the link to the spontaneous ideas and conceptualizations of the students takes place. It has been inspired on several works about Science Modelling and Learning Progressions (Hernandez, Couso and Pintó, 2015).

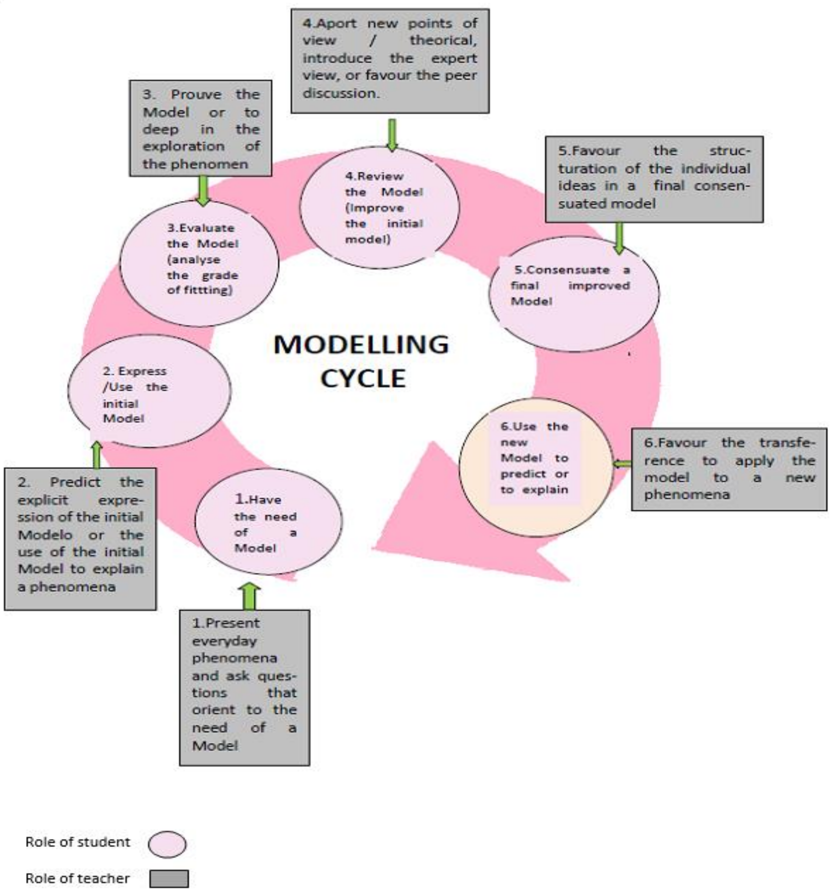

Figure 2. Science Modelling Cycle (Couso and Garrido, 2016)

A question may be asked here in relation to the context: **Where** is the Context in the *Modelling Cycle*? The answer is not immediate, the context could be a partial context in any of the stages or steps, but also could be used larger contexts taking together more than one step. Or could be also the inspiration for a wider context of the entire TS approach, among other possibilities.

The Activities into a Teaching Sequence Based-in/on Context

A TS is designed through the activities or tasks that students have to carry out when the TS is applied to school. So, models to analyse and design activities are very relevant when we try to introduce the context in the TS. We come from the work made in the LICEC-UAB group during some years about context and about activities in TS. It is relevant for us the document (not edited) Aliberas et al. (2015) *Dimensions of the Scientific Activity in School and the Context.* This document has been an important help to analyse and evaluate some activities that we propose in a TS based-in-context on Relativity of Motion in part 3. Central to this document is the Scheme of the Dimensions in Modelling a Science Activity for schools. The document has been elaborated in relation to the LICEC-UAB (2013-15) sessions about Context. The authors infer that the activities include six dimensions or characteristic aspects that can be differentiated between them, which are:

- **Physics** dimension: the *physics systems* implied
- **Cognitive** dimension: the mental scientific models or *mental representations* that student has to understand phenomena or problems and also the implied *emotions*.
- **Pragmatics** dimension: the identified *problems* and the *actions* to solve them. **Communicative** dimension: the *languages* (multimodal) to communicate intra and inter people about the dimensions.
- **Scholar social** dimension: the *scholar organization* to face the problems.
- **General social** dimension: the *social problems* shared with the social environment.

These dimensions are linked to the study of the activities carried on by students using the ONEPSI Model which idea fundamental is that students have to activate the necessary knowledge to build *satisfactory mental models* (Coherent, Corresponding, and Robustness) about a situation or problem (Gutierrez, 2001, Aliberas, 2012).

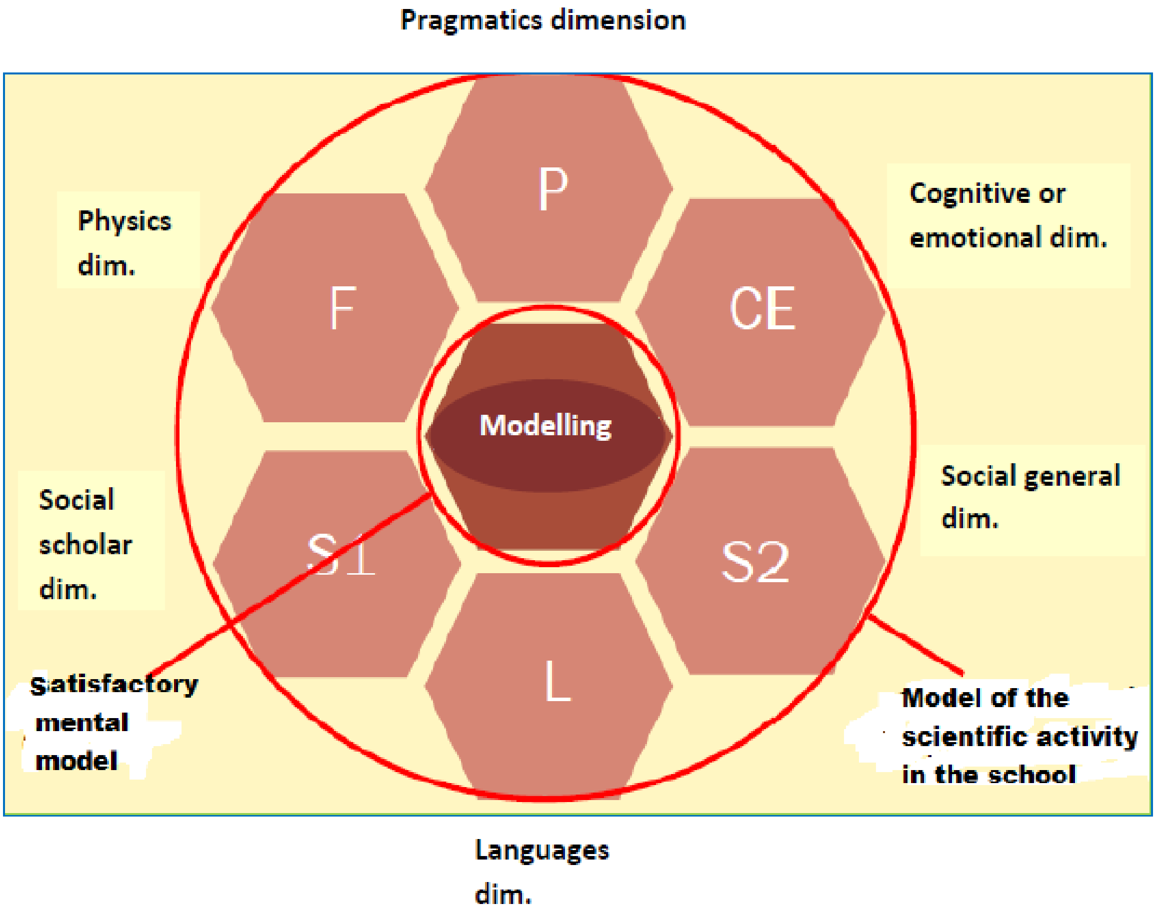

Figure 2. Dimensions in Modelling a Science Activity

Also there may be defined several *Levels of Contexts* that we summarize here (Table 1).

In fact, we put an order to the contexts using two dimensions: 1) specificity or generality – time of duration in the TS, and 2) implication of only one discipline or more than one. The **table 1** presents the crossing of these two dimensions.

Proposal and presentation of our study

We present here only part of a larger research based on the practice of teaching science-on-context. The theoretical reflection of our group based on literature and practice facilitates an agreement with the main criteria for a good context, and also several possible levels for contexts, in particular, when it is based on History of Science. These aims belong to this larger project of which our study is a part (see Acknowledgements). The aim related to this paper is the third one.

The proposal

To prove that a particular context from the History of Science (history of Galilean relativity) may be an *appropriated context* for the scientific activity in the schools, because it may agree with *the main criteria of being a good context*.

To show that *several levels of contexts* based on the history of Galilean relativity could be chosen

To illustrate in the particular case of Galilean relativity that the HS may contribute to several aspects or ways in Science Education, which means *different uses of HS* in the Science Teaching Sequences.

Table 1. Levels of Context in a Teaching sequence

Specific and short time and only one discipline	Con-text Levels	**Explanation of the context level.**
	C1	Context that ***inspires and orients*** the TS, but that it is not always present in all the activities. Could be grades of this, f. e., it *only inspires and orients*, it *inspires and orients and also it is used in some conceptual approaches* (f. e, definition of terms used).
	C2	Context of a **specific activity** of science.
	C3	Contexts of **a session** or **few linked sessions** of teaching/learning science in school.
	C4	**Initial context** of the Teaching sequence (that disappears after).
	C5	**Initial context** of the TS but that **appears once or several times at other several moments** of the Teaching sequence.
	C6	**Global context of an entire Teaching Sequence** (context related to sports to teach/learn about motion and forces; context of health to teach/learn about diseases or functions of human body, ...).
	C7	Context of a **Science Learning Project** (during a month or a trimester) (f. e., music produced by an orchestra: instruments production, sound propagation, sound reception related to music).
	C8	Context of a **Learning/Action Project** (during a month or a trimester, or longer period) in an **interdisciplinary way** (the new perspective of work–in-project-context with the inclusion of several subjects in a level or course) (f. e radioactivity or climate change from several aspects or disciplinary-interrelated perspectives, values, etc...). It could include also **proposals of actions** in the school or in the environment near to the students.
More global and larger time and several disciplines	C9	Context of a **Learning /Action Project** (during a trimester, semester or the entire course of nine month) by **collaboration of all the levels of the school** (f. e., there is a social problem near the school and the school collaborates to solve it with the active participation or collaboration of students with the help of the work carried on in several disciplines/subjects and with the collaboration, also, of the students from several levels and, perhaps, with the help of their families).
	.....	

The Teaching Science based on the History of Science

The most relevant question to ask here is: Could a context-based on HS be considered an appropriated context in Secondary Education level? Looking for in the literature examples of Teaching Sequences based-in/on-Context of nowadays, not many are contexts based on HS, especially at the level of Compulsory Secondary Education. To reflect about this aspect, we use some instruments presented in section 1.2.1, and also, we look for in the literature examples of Teaching Sequences based-in/on Context of nowadays and the uses given in these to the contexts (Mattews, 1991). We collect the main uses of context in the below list. We consider that these uses may be "indicators" to think about types of context based on HS.

Uses of HS in Science Teaching. Ideas for uses of HS as context.

U1: Fundamental **"Big Key Idea"** or Initial Question or Problem to design or to apply in a Teaching Sequence.

U2: Fundamental **Scientific models** with their **Sub-models (sub-key ideas)** in the development of Science that may be used to design a Teaching Sequence.

U3: Some **Expressions** of these fundamental **Models** and **Sub-models** in a **narrative way** or by means of some **languages** that might be not so far to the students thinking and representations in contrast to some more formal languages in the science textbooks of nowadays.

U4: Main **Difficulties** or **Epistemological obstacles** (Bachelar, 1958) in the development of the science that may help the teachers to understand the thinking and the learning difficulties students have.

U5: Paradigmatic Facts (experiments to be done in classes or laboratories) that may be used nowadays in a, perhaps, more modern version, to ask the students to interpret them by building their **own models** and later **reviewing them** with their application to other facts or problematic situations from the HS or from nowadays contexts.

U6: Interesting "histories" for the **engagement** of students to the science, to the HS and to the knowledge of their local HS or social/politics history that facilitates scientists and citizens to dialogue about **values** and **ethics**.

And so on … **U7**…

This knowledge is much appreciated and gives us an open perspective of the possibilities of HS as a Context in the teaching of science.

A Teaching Sequence Based on an Historical Context: The Galilean Relativity

The approach of this paper comes from our research and teaching experience in the Pre-service Primary Teacher Training Grade, and from the Seminar about Teaching Sequences in the Master of the Pre-service Science Secondary Teacher Training in the University of Barcelona (2013-2016).

The Teaching Sequence about Galilean Relativity

BIG question: Is the motion absolute or relative to other bodies? Or to systems?

The **BIG ideas about Galilean Relativity**: The motion of a body (system) is always relative to another body (system). The absolute motion doesn't exist, it doesn't have scientific meaning.

Fundamental concepts: They are two fundamental notions to face students in their learning about motion: "*What is motion?", "What is Frame of Reference?".* Are these notions easy?

What is Motion is not a very difficult idea but it is anti-intuitive or an everyday conception that is opposite to the one of the Physics, so students don't accept easily. *Frame of Reference (FR)* is a difficult notion, surely because the FR concept is a very abstract notion in Physics.

At the level of Primary and compulsory Secondary Education, we choose to introduce an approach to the FR concept based on the Bruno's and Galileo notion of *Mechanical System* (*MS*) (Tonnelat, 1973), which is more concrete and thus more accessible to our students. In *La Cena de le Ceneri* (1584) Giordano Bruno presents this notion of MS as an ensemble of animate bodies with the same motion related to same reference. A characteristic of this MS is that it is impossible to recognize the motion of this MS from the experiments performed inside it. This is also an important big idea that is in the *Dialogues* of Galileo and we introduce in our TS.

With Primary Teacher Training Students (and it can be done at high secondary school) we complete the FR notion of Bruno/Galileo with the one of Einstein, mainly based on some texts that illustrate very well the Physics' notion of FR (Jammer, 1970; Einstein, 1970). This notion of FR from Einstein is more abstract that the one of Galileo but much appropriated to better understand some problems of relativity of motion. Related to this conception, we have the useful notion of *Event* (event is something that happens in a particular point of a space in a particular instant of time), which will be used in our teaching proposal in a more visual and accessible way.

The sketch of the TS for secondary education

- Motion is a change of position relative to someone or something.
- Objects that do not move relative to others constitute a reference frame. (Equivalently, we can say that all objects that move in the same way relative to others constitute a reference frame). The motion of any body is the same for all these objects.
- The description of any motion is always relative to a frame of reference (FR).
- The motion of an object can be described relative to several FR. Motion changes when the FR changes.
- All objects that constitute an FR move in the same way relative to another FR (in particular, the carrier and the carried object). Due to their mutual relations, this shared motion is as if it did not exist. (This last idea is into a fragment of the dialogues of Galileo Galilei)
- The common motion of all the objects that constitute a FR is not lost when one of the objects of a FR is separated physically of this FR (The motion one object has by participating in the carrying motion is not lost when the object becomes separated from it).
- If a FR A moves respect to other FR B, the FR B moves respect to A with an opposed motion. That means, the motions relative one to other between two different FR are the same but opposite.
- We can interpret the motion of an object relative to a FR A as its motion relative to other FR B combined with the motion of this FRB relative to A.

The contexts in the Relativity of Motion TS

There are several contexts in this TS, but not all with the same use and at the same level.

The TS has been inspired by the *Dialogues on the Great Systems of the World* of Galileo Galilei (1632), being this the global context that has oriented all the TS. There are also other more everyday real or fiction situations used in the activities, and that may be a specific context of one or a set of activities as: 1) Bodies in motion without dragging between them (cars, trains, lorries, running man, bicycles, lifts, planets, Earth, etc….). 2) Systems and bodies in motion with dragging between them (boat in a current water of a river, man on a run belt, bodies moving into trains, bus…).

The levels of context in our TS are (from the identified categories in the Table 1):

CT1: Context that *inspires and orients* the TS, but which is not always present in all the activities. *The Dialogues of Galileo inspire and orients the TS, but also is used to the conceptualizations introduced and to inspire some activities.*

CT2: Context of a **specific activity** of science. *HS is the context of several activities*

CT3: Contexts of **a session** or **few linked sessions** of teaching/learning science in school. *Some sessions and some linked sessions have the context of HS.*

CT5: Initial **context initial of the TS but that appears once** or **several times at other several moments** of the Teaching sequence. *Our context linked to HS appears and disappears several times during the TS.*

These "contexts" may be introduced by several ways. Some ways may be dynamics as with the gestures of the teacher or of the students making actions on or with objects, but other have material support as transparencies on a projector, sheets of white and carbon paper (that mark trajectories of motions), videos, films, simulation software, fragments of HS texts or about HS (*Dialogues*, *La Cena de le Ceneri*, *The Evolution of Physics*, *The concept of Space*, and other...), histories, comics or other narrative texts, etc. Other ways are more static as the use of visual material support as images (photos, drawings, cartoons, comics, and other visual elements, ….).

In particular, from the *Dialogues* we selected the following fragments to inspire the approach, the activities or to be used directly or adapted in activities, they are from the Second Journey:

- Motions of the Earth are imperceptible to their habitants (p.114).

- The shared motion is like it didn't exist (p.115-116).

- First argument, from the weight bodies that fall down from a height (p.126).

- Law of Inertia (p.145).

- Remarkable phenomenon in the motion of projectile (p.154) and the text that is in relation to it and that is from Giordano Bruno (1584) *La Cena de le Ceneri* (3rd day).

- The ball that runs behind the horseman (p.155) (p.516)

- The surprising example of Sagredo of the infectivity of the shared motion (p.171)

- Why does it seem that the cannon's shuts to West go farther than the ones that go to East? (p.168), *The problem of Tyco Brahe*

- Experiment that invalidates all the experiments presented against the motion of the Earth (p.186) (p.547)

We will present some of the built problems and activities as illustration of the work we are doing. The specific context of several activities is the HS using or adapting fragments of the *Dialogues* of Galileo or of *La Cena de le Ceneri* (1584), but not in all the activities proposed in the TS the specific context is HS.

Some examples of activities in the steps of the Modelling Cycle

First step: **To have the need of the Model.**

Key ideas: Motion is a change of position relative to someone or something; objects that do not move relative to others constitute a FR (Equivalently, we can say that all objects that move in the same way relative to others constitute a RF). The motion of any body is the same for all these objects; the description of any motion is always relative to a FR; the motion of an object can be described relative to several FR. Motion changes when the FR changes; all objects that constitute an FR move in the same way relative to another FR (in particular, the carrier and the carried object). Due to their mutual relations, this shared motion is as if it did not exist. (This last idea is into some fragments of the *Dialogues* of Galileo Galilei: *Motions of the Earth are imperceptible to their habitants* (p.114); *The shared motion is like it didn't exist* (p.115-116))

HOW? Initial written qualitative problems are proposed to students as exploration of the conceptions of students, in particular the problem of the "*man with a tyre"* is proposed in the stage of building the scientific model of Relativity of the motion:

Problem of "The man and the tyre":

Imagine that you are floating with a tyre in the middle of a river and not swimming. Some up river metres there is a box of wood that floats and some river down metres there is another box.

a) If you are floating without to swim, the distance between you and each box will change with the time? Why?

b) You can suppose the tyre let the air out. To which of the two boxes would you go to arrive before? Why?

Students try to solve this problem. They present some answers and we ask: Why? Justify your answer. With the discussion about the solutions and with the recourse of transparencies, through the first activity of the *man and the tyre*, students may build the scientific model with the support of the teacher. Specially related to the second question, students give several solutions but their arguments are in many cases based on their intuition only. Teachers may help the students to build a "correct" solution using the resources of **transparencies** (Figure 3).

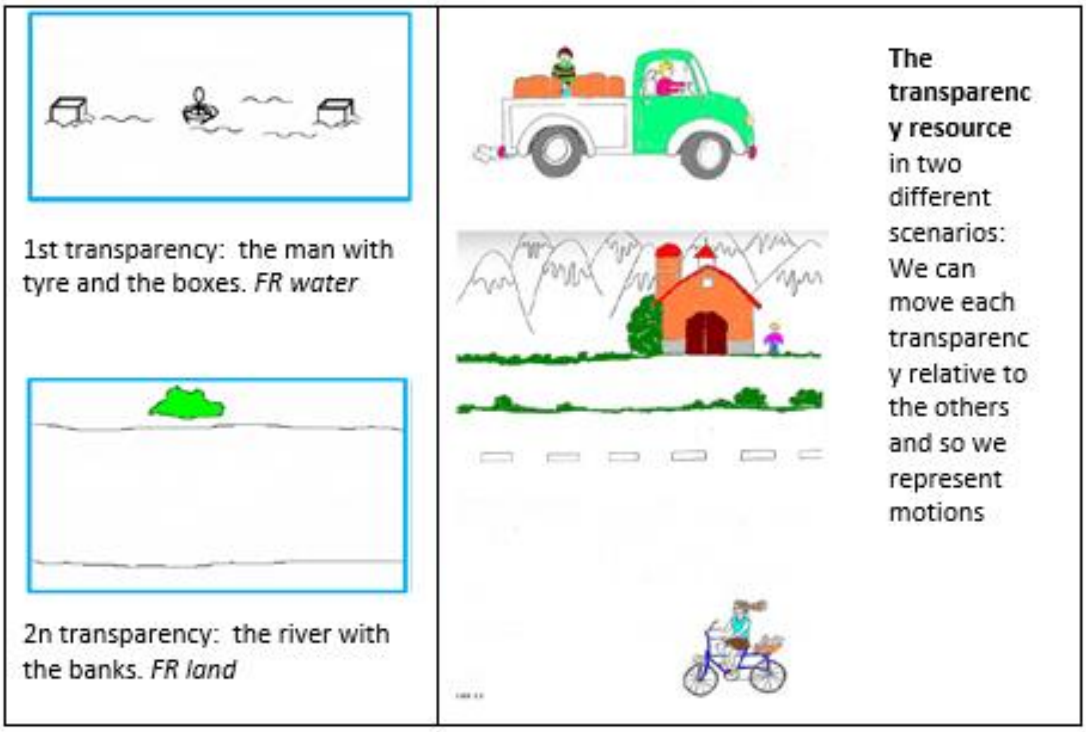

Figure 3. The transparency resource in the study of the relativity of motion

Fourth, Fifth or sixth steps of the Modelling Cycle

We present here an activity that may be for the step 4 (*Review* the model), 5 (*Consensuate* the *new Model)*, or (6) *Use the new model to explain a new phenomena*. The TS would be adapted to every school or group class.

It is a new problem, *The ball that runs behind the horseman,* based on the *Dialogues* (p.155, p.516). The text in the Dialogues is copied in the Appendice. The problem is presented in a **written text** inspired and adapted from the original fragment of the *Dialogues* of Galileo.

One of the passages of the book "*Dialogues about the two Great Systems of the World"* (1632) written by Galileo Galilei concerns to the ball that run behind the horseman (The text of the Galileo will be given to students).

a) The first point of disagreement in this passage between Simplicio and Salviati (Two characters of the Dialogues) refers to what does would pass to a ball that a horseman riding uniformly leaved from his hand without given to it any pushing. According to Salviati, "once the ball arrived to ground it wouldn't stopped there but it would follow moving to ahead as the horseman and if we don't consider the friction between the ground and the ball, the ball would advance at the same velocity as the horse moves, on the opposite Simplici says that this wouldn't pass but the ball would rest behind relative to the horseman, except if the horseman thought the ball violently in the direction that he advances. Which of the two characters has the right answer? Justify your choice using the relative Kinematics model built in Physics classes (FR; velocity relative to…..).

b) The second point that is in the dialogue between Salviati and Simplicio in which Salviati present the problem about if the horseman (riding with a constant velocity) throws a ball in the opposite direction to the one of the horserace, this ball, once to land, although that thrown in opposite direction, would follow, in some cases, the horserace direction and it would be rest stopped on the land in other cases, and it wouldn't go in the opposite direction to the horserace, but only in the case that the motion that it had received from the arm of the horseman surpassed in speed the one of the horse. Would you agree with the statements of Salviati? Justify your agreement or disagreement using the relative Kinematics model built in Physics classes.

This problem can be proved with an easy activity in the classes: A student that is walking rectilinearly let fall out a ball, the ball when hit the ground follows moving in the same direction of the student' motion, similar to the case of the horseman in Galileo's Dialogues. The problem and the experimental activity may help the students in the strong difficulty they have to accept that *the motion one object has by participating in the carrying motion is not lost when the object becomes separated from it.* Here the **resource is a simple experiment** done by a student in front of the class. This activity may be completed with the same activity but with the recording of the video of a boy that walks and throws a ball while is walking. Here we use the resource of the video (Figure 4).

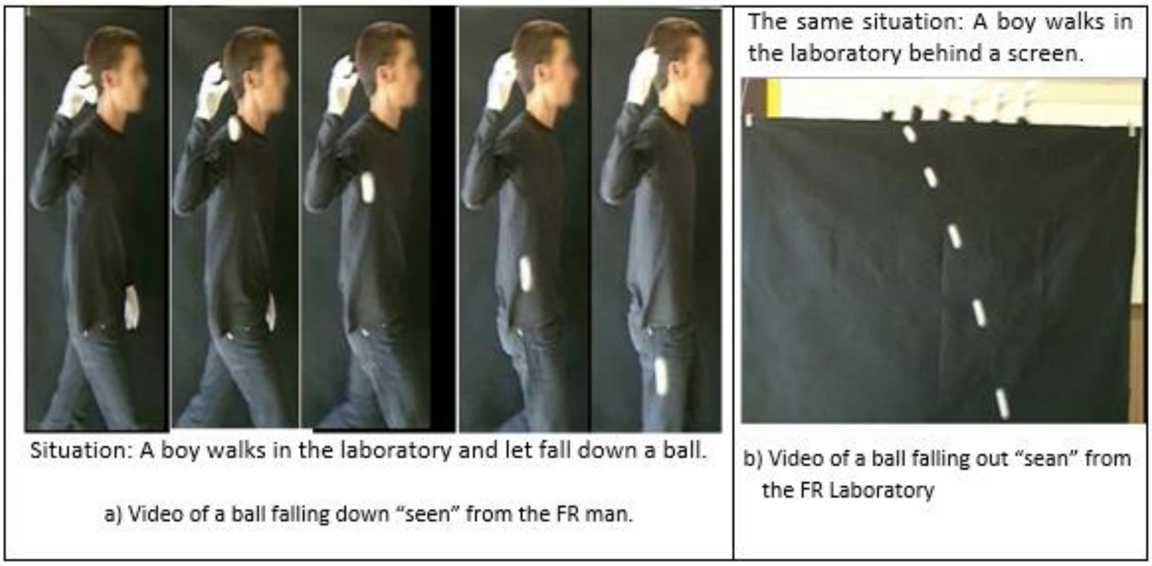

Figure 4. Videos of ball throwing from a man walking in the laboratory "seen" from two different FRs.

Conclusion

The experience carried on with the use the History of Science as a context in a particular Teaching sequence seems to demonstrate that this is a good context to be used in several ways and levels at Secondary Education or Teachers' Training of Primary or Secondary Science Education. We have used this context based on the HC focusing on the history of the Galilean relativity during several courses in the Pre-service Primary Teachers Training Grade, and more recently, in Pre-service Secondary Education Teacher Training Master. In both educational contexts, students recognized they have learnt about Galilean relativity in an interesting way that they never experienced before. Students' answers to an initial questionnaire were collected and the results compared with answers to post teaching questioner, and although a qualitative analysis of the students answers show that the topic is not easy to the students, they improved their conceptual understanding of Galilean relativity, but not only this but also about HC and about the process of construction and evolution of the scientific knowledge. We don't present here results of the questionnaires because there are too much and we evaluated more the qualitative debate carried on with the students at the end of the TS application.

If the teaching science in context using HC is good for the students' learning, a first consequence of this appreciation is that we have to think about how the Teacher Training has to be re-designed in order the teachers may be able to teach science based-in/on-context that favourites the science knowledge transference using History of Science.

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