BOLD VISIONS IN EDUCATIONAL RESEARCH

Crossing the Border of the Traditional Science Curriculum

Innovative Teaching and Learning in Basic Science Education

Maurício Pietrocola and Ivã Gurgel (Eds.)

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Crossing the Border of the Traditional Science Curriculum

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Crossing the Border of the Traditional Science Curriculum

Innovative Teaching and Learning in Basic Science Education

Edited by

Maurício Pietrocola
School of Education, University of São Paulo, Brazil

and

Ivã Gurgel
Institute of Physics, University of São Paulo, Brazil

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To my father, who never gave up until the very end. (MP)

To my wife, who encourages me to continue in
every challenge I face. (IG)

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Crossing the Border of the Traditional Science Curriculum is a collection of chapters, the authors of which have been participants in projects supported by the Curricular Innovation Research Center (NUPIC, in Portuguese) at the School of Education of the University of São Paulo between 2003 and 2012. We want to thank the Foundation for Research Support of the State of São Paulo (FAPESP), the National Council of Research (CNPq), and Coordination for the Improvement of Higher Education Personnel (CAPES) for their support of NUPIC and its projects.

INTRODUCTION

The introduction of curricular contents normally absent from science classrooms is not a simple result of the will or desire for curricular updating, but emerges as a complex issue to be addressed in the context of applied educational research. This book came about from research projects developed between 2003 and 2012 at the University of São Paulo by NUPIC[1] and financed by the public research and development agencies FAPESP[2] and CNPq.[3] The focal point of these projects was investigating the introduction of knowledge from modern and contemporary physics (MCP) as a process of innovation meant to transcend the educational processes already established by didactic practice and tradition. In this context, we developed many research studies, with the main goal of studying the limits and possibilities for introducing these contents to high schools. At first, two physics subjects were privileged in this process: (I) the dual nature of light and (II) the physics of elementary particles. This research was followed by other themes, including the history of science, relativity theory, radiation, cosmology, and astrophysics.

Parallel to this framework, we developed other lines of work aimed at understanding possible impositions in the processes which generated the theoretical results of the research, taking into account the construction of didactic activities/sequences of teaching and learning; the epistemological characteristics of knowledge, such as creative imagination; the structure of scientific knowledge; the nature of science; scientific explanations; and scientific narratives.

These studies generated various results, some practical, such as didactic materials for teachers (available on the group's website as Sequences of Teaching and Learning) and in-service courses for high school science teachers, and other, more-theoretical ones, in the form of articles and conference presentations. In addition, these studies allowed the group to participate actively in the construction of Physics Curriculum Standards by the State of São Paulo (São Paulo, 2008).[4] In terms of theoretical results, some working hypotheses emerged from that stage of research. We believe that the problems faced in updating the physics curriculum can be understood in terms of two distinct yet complementary kinds of impediments, which we define as didactic-epistemological obstacles and didactic-pedagogical obstacles.

(I) Bachelard's (1938) original idea of epistemological obstacles relates to the notion that the development of scientific knowledge stems from thought surpassing itself. The obstacles proposed by Bachelard were limited by a few types which were especially appropriate in addressing the formation of the scientific spirit (esprit scientifique), defined by him as that which is present at the birth (17th century) and the maturing (19th century) of modern science. In our theoretical perspective, didactic-epistemological obstacles are ways of understanding the ruptures present in the production of scientific knowledge vis-à-vis the educational system. In other words, our goal is to encompass and expose the many types of epistemological inadequacies present in the process of didactic transposition, as related to the structuring and development of scientific knowledge itself.

Proposing the existence of didactic-epistemological obstacles notably tied to the didactic transposition of modern physics, as differentiated from those tied to classical physics, results in the following hypothesis:

> *Classical physics is a knowledge developed on the basis of a phenomenology present in everyday life, whereas modern physics results from the exhaustion of classic ideas.*

The same could be said of other scientific areas, such as chemistry, biology, astronomy, and even geology.

So far, we have proposed the existence of four types of didactic-epistemological obstacles related to modern physics, namely: phenomenology, language/ formalization, conceptual structure, and ontological base. To be succinct, each of these obstacles is based on the difficulties observed in the construction of knowledge for teaching intended for high school education. We briefly describe each of these obstacles below.

Phenomenology – Most phenomena making up the contents of classical physics are accessible in everyday life and/or in didactic laboratories in the form of simple experimental activities. The phenomena considered in modern and contemporary theories belong to a world beyond the limits of daily life: the very small, the very fast, the very old, etc. Such phenomena are neither accessible to everyday life nor prone to being presented in simple experiments in didactic laboratories. To wit, while a drip that creates a circular ripple in a lake or a bowl with water can be used to start a discussion on the concept of wave mechanics, which readily-available tools might be used to discuss the dual nature of light?

Language/formalization – Most of the contents of classical physics can be transposed to the school environment via a simplified mathematical formalism, comprised of basic algebra and geometry. Conversely, modern and contemporary theories are structured by the use of complex mathematics, such as the functions of probability, tensors, etc. There are no high school-centric didactic transpositions which lighten the mathematical knowledge requirements for such contents. This type of problem has been addressed in the literature in two ways: either by demanding the necessary technical expertise, or through choosing more conceptual and qualitative physics, often using metaphorical and analogous methods.

Conceptual structure – Scientific concepts can be understood as an abstract extension of concepts present in common knowledge. Determining factors such as force, temperature, heat, and energy are examples of equivalent concepts in the context of the world's intuitive knowledge. Such concepts were/are the focus of research on misconceptions and cognitive development. The concepts present in modern and contemporary physics breach common ideas and, more than that, are counterintuitive, running opposite to the basis of human knowledge. Probabilistic determinism, orbital position, concepts of spin and reduced mass, as well as relative time and space, are terms liable to be associated with intuitive concepts. However, they should be understood as "old language graveyards".[5]

Ontological base – Classic entities are built from objects present in the perceivable world: particles, waves, space, time, energy, etc. The entities present in modern and contemporary theories are constructed opposite to common sense: particles with no mass, quantum energy, virtual particles, and curved space are entities which contain special characteristics, properties, and behavior highly distinct from the objects that make up everyday life.

(II) The concept of didactic obstacles was proposed by Brousseau in 1986 to indicate the existence of teaching practices, habits, and didactic foci which hinder the process of teaching and learning. Similarly, we will use the notion of didactic-pedagogical obstacles to define the conditions of the didactic system which hinder/prevent the introduction of contents from modern and contemporary physics. These conditions were forged over the 200-year history of physics teaching and if, on the one hand, they contribute to the establishment of classical physics in classrooms, they are on the other hand obstacles to the introduction of certain knowledge.

The notion that didactic-pedagogical obstacles exist stems from the hypothesis that:

> *Classical physics teaching is the fruit of a process of didactic transposition validated by a historical process.*

Over the centuries, trial and error have selected contents, defined activities, perfected evaluation methods, and created a school curriculum adjusted to the educational system, making it highly stable.

The didactic-pedagogical obstacles to the introduction of modern and contemporary theories in high school are the conceptual hierarchy of prerequisites; the didactic intuition of teachers; content selection; proposed activity types; and evaluation.

Each of these obstacles is derived from the difficulties observed in the construction of knowledge taught related to modern and contemporary physics for high school education. These obstacles are briefly described below:

The conceptual hierarchy of prerequisites – indicates that the simplest concepts should precede the more complex ones. This belief is tied to the idea that the history of physics serves as evidence of a growing conceptual sequence – and thus hinders the consideration of 20th-century theories as a basis for didactic transposition. In this perspective, newer knowledge is conceptually dependent on older knowledge and the former cannot be taught without the latter.

The didactic intuition of teachers – holds that there is an intuitive method of teaching physics, which is manifested in the practice and the speaking of teachers and students. This practice suggests that physics teaching inherently contains, for example, closed problems and exercises. It also indicates didactic tools which are not configured/included as physics teaching, such as certain texts and conceptual questions.

Content selection – The contents of traditional physics programs are historically validated and ready to be taught. Innovation by seeking new content involves taking risks, which is often seen as devoid of merit.

Proposed activity types – As with curricular contents, there are exemplary activities which are assumed to "work" in physics teaching and learning inside class rooms. For example, solving problems – an approach widely studied and researched in the field – is considered an exemplary method of developing activities in physics classes. This premise becomes clear when attempts are made to change school routines by incorporating different activities, such as project-based learning, etc.

Evaluation – Finally, evaluation is one of the most sensitive aspects of classroom management. In classical physics, there is a consensus around what and how to evaluate. Changes in school knowledge often render traditional methods unfeasible, creating resistance.

The transposition of modern science contents to high school classrooms should be seen as one of the most complex tasks facing educators. On the one hand, there are the inherent epistemological demands in the field of scientific knowledge, demands which are very distant from the standards of understanding forged in everyday life. On the other, the demands of the school environment are equally challenging: ideology, intertwined with didactic and traditional necessities, constructs its own set of pedagogical complications. The result is a complex problem with no obvious solution: How might both domains be satisfactorily addressed? Is it possible to maintain conceptual rigor while simultaneously meeting the demands of the teaching and learning system?

Such questions must be answered through applied research, in the form of proposals for and analyses of classroom activities. It is important at this point to highlight those research contexts capable of revealing the didactic knowledge required to face such a challenge. We must also note that this process is not just a matter of addressing proposals for the insertion of new material within the known standards of teaching. The insertion of new scientific content in high schools should be seen as an activity of innovation, given that it involves rupturing a tradition of education that precedes teachers, students, curriculum shapers, etc. That being said, it will be important to recall the thematic of curricular innovation in educational lore.

Aside from the works originating in the above research projects, several additional chapters were included in this volume because they share the same desire of crossing the borders of traditional science education. These explore themes related to the use of educational robotics, computer simulation, and the coming together of art and science.

Almost all research took place in Brazilian educational environments. The only exception is the chapter by Víctor López and Roser Pintó about computer simulation in Cataluña.

We hope this book offers fresh ideas about the limits and possibilities for change in science classes and contributes to methods of education that meet the demands of the modern citizen.

NOTES

1 This research group is self-entitled NUPIC – Núcleo de Pesquisa em Inovação Curricular (Curricular Innovation Research Center) – and it groups researchers from the Faculdade de Educação (School of Education), the Instituto de Física de São Carlos (Sao Carlos Physics Institute) of the USP (University of São Paulo), the Physics Department of UDESC, and the Physics Department of the Universidade Estadual de Ilhéus (State University of Ilheus), along with various graduate/postgraduate students and associated researchers. Further information can be found at http://nupic.iv.org.br/portal.

2 FAPESP – in English, the Research Support Foundation of the State of São Paulo.

3 CNPq – in English, the National Research Council.

4 Physics Curricular Standard of the State of São Paulo.

5 Referring to the growth of languages, Russell (2001) states the following: “The common language is a graveyard for the remains of the philosophical speculation from the past”.

MAURÍCIO PIETROCOLA

1. CURRICULAR INNOVATION AND DIDACTIC-PEDAGOGICAL RISK MANAGEMENT

Teaching Modern and Contemporary Physics in High Schools

INTRODUCTION

The text that follows is focused on the uncertainty related to the selection and creation of scientific knowledge for the classroom. Although a wide range of aspects of science can be found in school contents, traditional teaching over the past decades has favored those contents needed for problem solving (Echeverría & Pozo, 1998; Peduzzi, 1998). Since the 1950s, several studies have evaluated the relevance and possibility of curricular innovations which diversify the school content beyond problem solving (Barojas, 1998). To that end, it has been commonplace to encounter works proposing alternatives to this method of conceiving of potentially-teachable science contents, particularly when distinguishing between knowing what science is, knowing about science, and knowing about the uses of science (Hodson, 1992). Works focused on teaching the nature of science (NOS) exemplify attempts to broaden the scope of relevant options for school content in high schools (Gauch, 2009; Niaz, 2009; Park & Lee, 2009; Abd-El-Khalick et al., 2008; Schwartz & Lederman, 2008).

Within this context of questioning what types of scientific knowledge should be taught, the contents that stand out are those aimed at analyzing the role and importance of such knowledge to the basic formation of a social conscience in the individual (Fourez, 1994). Since science exerts an increasing influence on everyday life, the comprehension of its contents is fundamental to understanding the modern world and to active and full participation in today's society. We live in an increasingly technological society, a world brought about by the industrialization that was driven onward in the 20th century by scientific theories which took stands against the mechanistic thought long considered the paradigm of how to know the world. Theories such as special and general relativity, quantum chemistry, and molecular genetics gave rise to new fields of knowledge, leading to unexpected paths in scientific research and creating new technologies that up to that point had existed only in science fiction movies. The technological devices born from this scientific development changed behaviors, dictated rules, and, also, created doubts and expectations concerning the role of science in modern society.

Today, we are able to access many products and processes created by contemporary technology, with digital TVs with 3D imagery entertaining us at home, medical equipment that makes remote surgery possible, and so on. However,

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very few of us manage to overcome immediate feelings of awe at the spectacle offered by science. In general, it is neither possible for the average citizen to comprehend the products of new scientific advancements, nor to decipher even a fraction of the information received from the media. Even in the 21st century, many respond to the new reality as our prehistorical ancestors did to fire. Thus, we face the paradox of living in a society which has science and technology as its prime engines yet where nonetheless a large portion of the population remains scientifically and technologically illiterate.

More than twenty years ago, Gerard Fourez explored the political, social-economic, and cultural factors permeating education, taking into account the possible impact and transformation that might result from teaching science in a way that promoted the Scientific and Technological Literacy (STL) of the student (Fourez, 1994). He stressed that STL could be a compass for science teaching in the context of the "crisis in science teaching for citizenship". This crisis would have been already-discernable in a variety of initiatives demonstrating the inadequacy of science teaching in the face of the challenges of modern society. Examples of such manifestations include the catchy slogan, "A Nation at Risk", proposed by the National Science Teacher Association (NSTA) in 1980 and UNESCO's Project 2000+, founded in 1993. More recently, the Next Generation Science Standards (NGSS) echoed this train of thought by stating:

> The world has changed dramatically in the 15 years since state science education standards' guiding documents were developed. Since then, many advances have occurred in the fields of science and science education, as well as in the innovation-driven economy. The United States has a leaky K-12 science, technology, engineering, and mathematics (STEM) talent pipeline, with too few students entering STEM majors and careers at every level – from those with relevant postsecondary certificates to Ph.Ds. We need new science standards that stimulate and build interest in STEM. (NGSS, 2013, pp. xiv–xv)

Such a feeling of crisis is not limited to the last 40 years. The 1960s became known in science education lore as the "project era" for agglutinating many science education proposals in response to the demands of the time. This led to the development of many international projects such as the Physical Science Study Committee (PSSC), the Biological Sciences Curriculum Study (BSCS), the PILOTO by UNESCO, the Harvard University Physics Project, and the Nuffield Science Teaching Project, among others. All of them followed the perception that the science curriculum, more than any other field of knowledge, was burdened by social and political pressure to change in order to adapt to modern challenges and needs. Aside from the demands originating from society itself, there were often internal demands from science itself as a field of knowledge. On the one hand, it is acknowledged that scientific knowledge is in constant evolution and transformation; this suggests a periodic need to rethink the content being taught. On the other hand, there is the awareness that teaching science is no small task, one which always bears the inherent risk of inefficiency in the process. Teachers and educators in general are perpetually conscious of the success of their teaching, either in terms of the motivation and interest of their students or in the relevance and utility of their curricular contents.

In the last decade, and with Europe at the forefront, a number of projects such as STTIS,[1] Material Science,[2] NINA,[3] and the CAT European Project[4] have revived this demand for renovation with proposals for curricular innovation/update.

In Brazil, a similar discussion of science education goals appears in the PCNEM[5] (National Curriculum Parameters for High School), which uses the change of environment created by modern science and technology as justification for a change in the curriculum and presents goals to be achieved to promote education for citizenship.

The new technologies of communication and information permeate daily life regardless of physical space, and create conditions of life and coexistence in need of study within the school environment. Television, radio, and information technology, among others, have allowed people to approach the images and sounds of once-unimaginable worlds (Brasil, 1999, p. 132).

In this context of modifications produced by science and technology, physics has a prominent role. In the last century, the number of innovations and theoretical breaches in the field reached a very large number compared to other periods of its history. Physics is considered “the representative of science” par excellence (Emter, 1994) and the physics theories developed from the 20th century onward are the most successful description of physical nature elaborated to this day, while also having served as philosophical bases for important introspection on our methods of learning. The spectrum of physical knowledge, both in the micro and macro senses, was broadened in response to breaches between classic concepts and definitions and new ones. Theories such as general and special relativity and quantum mechanics served as the groundwork for the output of knowledge in a new scientific panorama.

Regarding this, the PCN+ (Complementary Educational Orientations to the National Curriculum Parameters for High School) demonstrates the ratification of what was shown above:

> The presence of physics knowledge in high school gained a new meaning from the directives presented in the PCNEM. It is about constructing a vision of physics focused on the formation of a modern, active and cooperative citizen, with the tools to understand, intervene and participate in reality. (Brasil, 2002, p. 1)

The Science Curriculum Standards by the State of São Paulo highlight the role of science in modern society:

> [C]urrent society, faced with matters such as the quest for productive modernization, concern for the natural environment, the search for new energy sources, and the choice of standards of telecommunication, needs to make use of the sciences as providers of languages, tools and criteria. Therefore, the basic education that ends in high school must promote

> scientific and technological knowledge to be learned and mastered by citizens as a resource of their own, rather than "of others" whether they're scientists or engineers, and used as a source of expression, a tool of judgment, decision making or problem solving in real scenarios. (São Paulo, 2008, p. 37)

The contents of modern and contemporary theories of physics are already part of our daily life and common sense, as there are indications of the existence among contemporary youth of alternate conceptions regarding certain topics of modern physics (Paulo, 1997; Pietrocola & Zylberstajn 1999). The production of these alternate conceptions must result from the interaction between the student and the world as modified by science and technology, especially as related to information put out by the press. In other words, it is already possible to acknowledge today the existence of an everyday world modified by modern science, a change similar to the 19th-century transformation caused by the advent of heat-powered machinery or that which occurred in the 20th century with the incorporation of electricity into ways of life and production in cities. It is to be expected that science education should enable individuals to incorporate the new products of science into their bag of knowledge, in a way that allows them to understand the existing stalemates, challenges, and achievements in society.

Faced with this scenario of specific demands and necessities in terms of knowledge, schools have been unable to properly deal with modern and contemporary physics theories. High school physics in particular has focused on knowledge related to theories from the 17th, 18th, and 19th centuries. The indexes of didactic books or school programs for physics courses display a structure that approximates their historical development stages: they invariably start with the study of cinematography (end of the 17th century), continuing with dynamics, hydrostatics, and thermology (18th century), reaching as far as thermodynamics and electromagnetism (19th century) in the final stages. This curricular organization reflects a linear and hierarchical conceptual structure, since it considers the "old" as preliminary. It implicitly holds that the student must undergo the historical trajectory of knowledge building as a field of scientific research. In this conception, it is only possible to teach contents such as electromagnetic field (from grade 12 of high school) to someone who was able to learn Newtonian physics (from grade 10).

This way of conceiving the curriculum has prevented science education from advancing beyond the borders of the so-called classical theories (those produced up to and through the 19th century). The image of science constructed by high school students does not match the activities occurring in laboratories and research centers. Even 35 years later, I recall an enthusiastic 15-year old high school physics student who asked me about university research into "Kinematics". It took me a few seconds to ponder the purpose of his question until I realized that, for him, the physics taught in class – based on problem solving for the movement and launching of objects – was an example of how physics were conducted in research laboratories. I do not recall what my response was, but I surely lacked the courage to disillusion him by saying that probably nothing fundamentally new had been produced in this field of physics since the 17th-century works of Galileo and Torricelli![6]

By limiting itself to classical knowledge, school physics hinders holistic scientific formation, because – even with the continued relevance of classical physics to certain technological areas and the prerogative of building a founding knowledge of western culture – the absence of modern and contemporary theories in class distorts the image of physics conveyed. The need to ensure people's understanding of the scientific-technological artifacts of everyday life, whether they are material or cultural, real or virtual, makes it imperative to proceed with a curricular update that ensures access to the contents present in modern physics theories developed throughout the 20th century.

The challenge to be faced thus far lies in understanding why schools have so much difficulty in inserting new contents –some of which have been in the past for over a century – into their didactic-pedagogical practices. We must find ways to move some ideas forward and suggest strategies capable of overcoming this unjustified discrepancy in such a scientifically-reliant society.

RESEARCH IN THE CONTEXT OF INNOVATION

In recent years, the subject of innovation has been a recurring theme in the international literature on science education research. Perhaps because of the large amount of update/renovation projects for school curricula in the last few years, this focus has been adopted by many researchers in the field, making it a point of study. These works are normally related to projects aimed at introducing and evaluating the impact of curricular innovation (Pinto, 2002, 2005; Ogborn, 2002; Piers, 2008; Mansour et al., 2010). Such projects are normally organized around proposals aimed at innovation, whether they are based on content, methodology, or the organization of teaching-learning activities. Many are dedicated to studying the role of teachers and their beliefs (Couso & Pinto, 2009; Henze et al., 2007; van Driel et al., 2005; Viennot et al., 2005) during processes of innovation. The *International Journal of Science Education* dedicated a special issue (Volume 24, No. 3) to research related to the STTIS project.[7] Roser Pintó, the guest editor, writes the following regarding the importance of the collection of research related to the project:

> The STTIS project aims at understanding the process of the adaptation of science teachers to their circumstances when specific innovations have to be implemented, in particular, the practice of some informatic tools in science classes, or some new images or graphs, or some new teaching strategies of specific contents. (Pinto, 2002, p. 228)

The 2008 edition of the GIREP[8] annual meeting, entitled "Physics Curriculum Design, Development and Validation" gave special attention to research related to curriculum innovation projects. The conference accepted works in eight lines of research, one being "Curriculum Innovations in School and University Physics". With sixteen coordinated sessions, this was one of the research lines with the highest number of works. Two of the eight plenary sessions were also dedicated to this theme. Something similar happened in two other conventions in the field, ESERA[9] and *Ensenanza de las Ciências*,[10] both in 2009. Each included coordinated sessions with works based on science innovation projects, mainly European ones.

A reasonable outcome in the face of this landslide of innovation research would be the institutional response to this science teaching crisis announced by Gerard Fourez (as described above). In other words, governments, aware of the frailty of their science education methods, should develop a financing policy for projects aimed at investigating innovation in science education.

However, this is nothing new in the field of education. Research on the subject appears in educational lore in the late 1960s, based on the themes of "institutional innovation" and "educational innovation", and often related to the use of the new technologies of the time (TV, slides, etc.) and the teaching of foreign languages. An example of a pioneering work in this field is Robert Bush and N.L Gage's (1968) "Center for Research and Development in Teaching", which describes research conducted at the Stanford Center for Research and Development in Teaching. Taken over by the behaviorist references of the time, the aforementioned research is founded on three variables of study: behavioral, or directly observable variables; personal variables, which can be inferred by tests; and, finally, institutional variables affecting the social, technological, and administrative elements of education. Among the latter, we have an emphasis on "studies of institutional scope involving the organizational context of education, the professional socialization of teachers and the attitude of teachers in favor of innovation" (1968, p. 1). Another work of this time comes from Thomas Stephens (1974), and is entitled "Innovative Teaching Practices: Their Relation to System Norms and Rewards".

New technologies are one of the points of interest in innovation studies to this day, with a large number of works evaluating their educational potential. Griffin (1988) studies the results of the use of computers in schools from the point of view of teachers. Wehrli (2009) studies the attitude of teachers toward the insertion of new technologies in class. Zhang (2009) attempts to study the learning culture as a complex system involving properties on macro and microscopic levels, the former being associated to beliefs and the very nature of behavior, and concludes that it is not enough to simply provide systems with "microscopic" properties (computers, software, etc.), since they cannot compensate for the other levels.

One author who stands out in the research about the processes of curricular innovation is Michael Fullan. In a classic book on the subject, he states that unsuccessful innovation attempts are based on models with no place for teachers' beliefs and practices (Fullan, 1982). For an innovation plan to be widely accepted, it is necessary to adjust it to the restrictions/limitations of teachers. In another study (Fullan, 2006), he states that, in innovation, the fundamental objective is to change the school culture; involved parties must organize innovation in the school culture context in order to make things clear not only in professional circles, but for student circles as well.

What draws attention in the bibliographic revision of this theme is the authors' strong insistence on the role performed by teachers in every process of innovation. In general, teachers are the most sensitive element of any process of curriculum innovation. One of biggest the risks involved is the lack of acceptance and/or understanding of such innovation on the part of teachers (Fullan & Hargreaves, 1992). The chances of success increase when the desire to change comes from within the education system, and is not perceived by the teachers as an imposition (Terhart, 1999). Innovation is faced with hurdles in the perceptions teachers have of their own ability/competence to innovate and in their willingness to assume innovation's inherent risks (Lang et al., 1999).

In the field of science education, there is a series of classic works about innovation (MacDonald & Rudduck, 1971; Brown & McIntyre, 1978; McIntyre & Brown, 1979). In the latter, entitled "Science Teachers' Implementation of Two Intended Innovations", McIntyre and Brown examine the first year of implementation of two innovations in science classes making use of education methodologies based on a mix of group activities and discovery methods. The conclusion is that teachers interpret proposals of innovation in a way that minimizes changes to their conventional teaching methods. Generally speaking, the important conclusion of these works from the 1970s is the certainty that including teachers in projects of innovation is essential. This is because innovating curricula and methodologies involves dealing with a variety of problems and assuming risks (Davis, 2003). Failure remains as a possible, albeit-undesirable consequence, as witnessed in the history of some of the most important science education projects such as PSSC and BSCS. Although teachers around the world consider these to contain excellent examples and good teaching materials, they were met with limited acceptance and short use in their original proposed contexts.

The early 2000s saw a number of articles aimed at addressing innovations in curricular content. This is because, according to their authors, the innovation of content is particularly important to science curriculum (Méheut & Psillos, 2004). Some propose dealing with curriculum innovations in this field via short- and mid-term studies, contrary to more traditional research, which requires long-term studies (Kariotoglou & Tselfes, 2000).

These studies were based on the methodological approach defined as Design-Based Research, or DBR (Design-Based Research Collective, 2003),[11] which is explained as a research methodology capable of associating theoretical research with practical and educational applications. The authors state the following:

> … design-based research methods can compose a coherent methodology that bridges theoretical research and educational practice. Viewing both the design of an intervention and its specific enactments as objects of research can produce robust explanations of innovative practice and provide principles that can be localized for others to apply to new settings. Design-based research, by grounding itself in the needs, constraints, and interactions of local practice, can provide a lens for understanding how theoretical claims

> about teaching and learning can be transformed into effective learning in educational settings. (p. 8)

The theoretical-methodological basis of the proposal rests on research based on intervention-analysis of results, often cited as "formative evaluation". However, it mainly seeks to overcome some of its limitations. This is because, in the traditional research of this line, the intervention of instructional programs, teaching materials, or pedagogical orientations of any kind, are measured by their contrast to pre-established standards (Worthen, Sanders, & Fitzpatrick, 1996). During such a "formative evaluation", cycles of intervention are based on development, implementation, and study, allowing the educational "planner" to obtain relevant information such as how intervention, successful or not, occurred, with the goal of maximizing the proposal being tested. The final result is an idealized proposal followed by a summary of the evaluation that ends up defining a context made of factors independent from the intervention that created them. The DBR works under the same perspective, using a mix of methods which allow the evaluation of results from an intervention. But, unlike "formative evaluation", the DBR conceives of the success of an innovative proposal as a product of planned intervention and in the context of the intervention itself, with the aim of going beyond the mere idea of perfecting a particular "product". In this sense, the intention of DBR in education is:

> to inquire more broadly into the nature of learning in a complex system and to refine generative or predictive theories of learning. (2003, p. 7)

The expectation of this group is to be able to develop successful innovation models beyond mere isolated artifacts or programs.

In the field of science education, a number of studies adopted this theoretical-methodological line in order to plan, apply, and evaluate sequences of teaching and learning of specific topics. An important characteristic of this line of study is to simultaneously address research and the development of teaching activities (Méheut & Psillos, 2004). In the studies by Lijnse (1994, 1995), we found a first mention of the paradigm of science education studies of this line. This generated the term *Teaching and Learning Sequences* (TLS). These studies may be understood as:

> … 'developmental research' involving the interlacing of design, development and application of a teaching sequence on a specific topic, usually lasting a few weeks, in a cycling evolutionary process enlightened by rich research data. (Méheut & Psillos, 2004, p. 516)

A special issue of the *International Journal of Science Education* (2004, Vol. 26, No. 5) compiles studies of this line. Among the articles included, Buty, Tiberghien and Le Marechal broach optics and conductivity, while Kabapínar, Leach and Scott (2004) address the subject of solubility. In another publication, Tiberghien et al. (2009) test a few epistemological presuppositions related to the process of TLS-based science modeling on the content of mechanics to 10^{th}-grade high school students. Besson and coworkers used the TLS perspective to conduct a study involving the concept of "physical attrition" (Besson et al., 2009).

Piet Lijnse and Kees Klaassen put forth an important discussion regarding the value of TLS-based research in a study from 2004. In this article, they introduce the idea of *didactic structures* as a product of applied studies involving TLS. The authors criticize the lack of studies dedicated to developing didactic knowledge of specific topics in favor of general educational theories or theories about cognitive learning. They state that studies involving sequences of teaching and learning wind up restricted to local scenarios and published in magazines targeted at teachers (2004, p. 537). They lament the surge of this type of research on international levels, since it could instead contribute to a real *didactic progression.* The authors harshly state that if we try to apply these general educational theories in an actual classroom

> one immediately faces the problem that, on application, such theories only result at best in heuristic rules. Such rules simply cannot guarantee that the teaching process that is supposed to be governed by them will have the necessary *didactical quality*. (italics added, 2004, p. 538)

The term "didactic quality" can be troublesome in the reading of the text, but the authors define this notion as follows:

> … although a best way of teaching a topic may indeed be an illusion, we do think that some ways are better than others; and therefore that it is worthwhile to search for evidence of how and why that is the case and for means that enable us to express and discuss the *didactical quality* of such teaching sequences and situations. (2004, p. 538)

They conclude,

> In this paper it is argued that the concept of 'didactical structure' might provide a further step to foster such deeper discussions about the didactical advantages and disadvantages of particular ways of teaching a topic. (2004, p. 538)

Finally, in the perspective of the authors, these very didactical structures would be the ones incorporating didactic quality in some form!

It seems fairly natural for us to state that the problems regarding the implementation of contents from modern and contemporary science theories in high school must be addressed from the perspective of content innovation. Aside from that, it seems the DBR's option, particularly through the TLS approach, would be an efficient method of providing safe guidelines to overcoming the risks inherent to the process of curricular innovation.

The TLS concerning modern and contemporary physics would consist of proposals for education resulting from the negotiation between demands of various types. The chart below, extracted from Méheut and Psillos (2004, p. 517), represents the existing points of interest in a general process of TLS elaboration. The authors use the term "didactic rhombus" and indicate two types of equally important complementary analyses: the pedagogical dimension and the epistemological dimension.

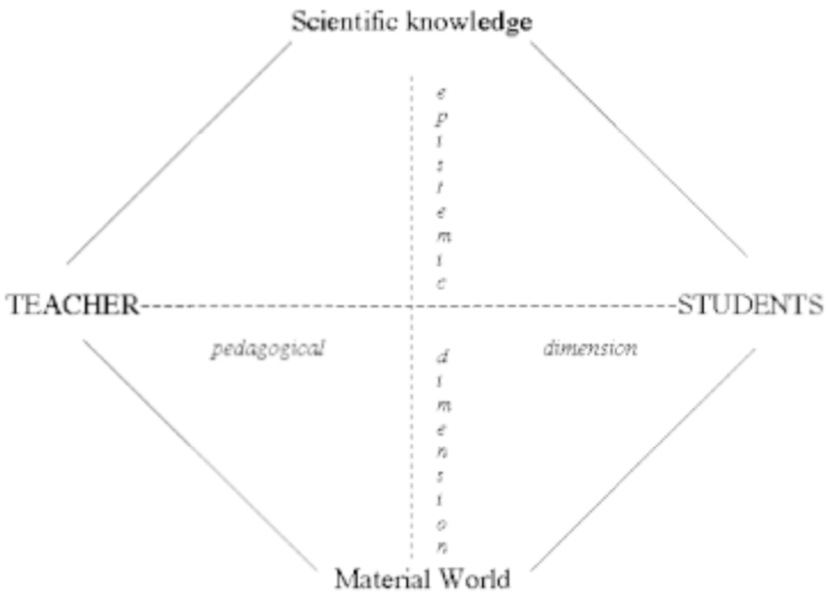

Figure 1. The didactical rhombus (from Méheut & Psillos, 2004, p. 517)

This perspective appeals because of the possibility of dealing with risks and dilemmas inherent in the process of innovation discussed above. The inherent epistemological demands in modern and contemporary physics (epistemological dimension – vertical axis in the above chart) and the classroom conditioning factors (pedagogical dimension – horizontal axis in the same chart) would have been considered in the studies. Therefore, it seems to us that this theoretical-methodological tool is well-suited to managing the didactic sequences produced, which would ultimately constitute the materialization of school knowledge as the focus of study. The didactic structures developed would incorporate the results of studies that could be seen by teachers as containing "didactic quality", making them an effective way of contributing to the update of the physics curriculum.

MANAGEMENT OF RISK TAKEN

However, the teaching of contents from modern and contemporary science theories has not been evaluated over time, as classical contents have been. In terms of didactic transposition, we could say there has been no therapeutic process for the evaluation of sequences of teaching and learning intended to provide some guarantee of learning by high school students. In other words, teaching modern and contemporary physics is a risk-taking activity, one involving the teaching of content that is vastly different from traditional physics lessons. More than twenty years ago, John Gilbert (1992) made similar comments concerning the risk taken by English teachers when engaging in an education project involving remote sensing by satellites. His main conclusion was that the more successful teachers were the ones with a high tolerance for uncertainty. In other words, resilience is an essential condition. But what makes a teacher resilient?

Some possible answers emerged from a study involving high school physics teachers in Brazil who implemented contemporary and modern physics courses. We studied how these teachers managed a situation of didactic innovation involving such contents. More specifically, the question we attempted to answer was: what is the perception of these teachers concerning the process of didactic innovation they participated in?

The study involved a research group of five teachers who worked on the implementation of TLS about the physics of elementary particles and the concept of wave-particle duality in the years 2007 and 2008. The production of this TLS had been initiated by another group of teachers and researchers circa 2003–2006. Therefore, the group was the second generation of teachers, and was facing preexisting teaching-learning activities. This group's profile is particularly relevant because it allows us to understand the conditions conducive to overcoming risks and understanding the mechanisms put in practice to increase tolerance of uncertainty. We wanted to understand how the available didactic material (in the form of didactic sequences) was appropriated and adapted by teachers, in order to put such materials to good use; and to understand the obstacles presented when teachers perceive new materials as foreign to their environment and their traditional practices.

We chose a qualitative approach aligned with the aforementioned international productions in accordance to the theme of curricular innovation in science. Faced with the similarity between our research goals, we used, in broad strokes, the methodological outline adopted by the project STTIS (Pinto, 2004).

Our data acquisition involved semi-structured interviews with the participating teachers. The interview protocol was based on five aspects: 1) reasons for participating in the project of innovation; 2) conception of modern physics education; 3) changes in professional practices; 4) obstacles and difficulties; 5) recommendations to colleagues in their profession.

The teachers' responses provided relevant information about their professional practices. A teacher stated that one "must be willing to do something different" (T4), later stressing that he "used to focus more on content and now I focus on other things" (T4). Another teacher stated that it is necessary to "have a different view [about] the possibility of developing a curriculum from another subject" (T5). We verified that the teachers had a predisposition to break away from traditional practices and attempt new strategies. However, we also noticed that this required them to expand on their formation. One of them recommended "continued study and discussion groups" (T1). Another stressed that "the teachers … must be aware they don't need to follow the curriculum rigorously" (T2). He further added that he felt prepared to "skip stages with no real loss" to arrive at modern physics. By the same token, another teacher stated that he started to "see the possibility of developing a curriculum from another subject differently" (T5). The latter statements express quite well the need for an initial and continued formation that grants the teacher a greater autonomy in his or her didactic choices. This also allows teachers to identify their own needs, as highlighted by one of those interviewed: "something I had to learn, had doubts, had to ask" (T5).

We categorized the teachers' responses as reflecting four types of perception about the process of implementing the modern physics contents they had participated in.

I. The perception that there is a tradition in physics education

The elements of the teachers' responses that resulted in this category were associated with a meta-reflection on their practice that allowed them to i) perceive themselves as part of a didactic tradition; ii) to realize that the didactic borders of the classroom are not so strict; iii) to acquire the disposition to break away from traditional practices and allow new strategies; iv) to understand that there are many options for contents – beyond the traditional contents – to be taught; v) to gain the perception that in order to teach modern and contemporary physics, one must be ready for new education scenarios.

II. The perception that something must change within the classroom

This category groups elements associated with the perception of: i) changes in how a class is conducted; ii) both students labeled as "strong" and "weak" changing their posture toward their interest in physics, relativizing the evaluations of good and bad students; iii) which subjects of interest to the students could be addressed; iv) what education could have done in terms of student skills and competences.

III. The perception that teachers must accept the risk of failure

The elements that defined this category were linked to the perception of: i) their own ability to manage the risk; ii) to be prepared to teach in a different way; iii) to assume the risks of change; iv) acquired self-confidence.

IV. The willingness to participate and find support in an innovative group

This includes elements associated with a teacher's need to: i) identify his/her own shortcomings; ii) be prepared to face problems; iii) be in a process of professional development; iv) have access to "experts" to deal with the complexities of a classroom.

CONCLUSION

The inherent risks and difficulties in a curricular innovation may be understood in terms of relevance and adaptation of knowledge to the education system. In this perspective, the construction of school subjects could be understood as the result of a process of didactic transposition, which transforms, implements, and judges in order to finally stabilize school knowledge according to the formative objectives and conditioning factors of the classroom. The traditional education of a particular school subject is the result of stabilized school knowledge, making it resistant to change. Risks and difficulties would be the expected consequences of innovation, with the latter experienced as a disturbance in the established order of an apparently stable scenario.

By analyzing the way that science courses are organized, it is not difficult to notice a prevalent logic of “school survivability”. Physics courses, like mathematics, chemistry, and biology, are the result of didactic transpositions initiated in a distant past that acquired certain stability as the result of classroom therapeutics. The proposition of change is therefore faced with tacit questions such as “Why innovate?”, “What to innovate?”, and “How to innovate?”, originated in the context of several years/decades of experience accumulated in the use of traditional activities. The context of this sedimentation of experiences has occurred in an education system, where the stage – the classrooms and didactic laboratories (teachers, students and their parents, among others), and the scripts – mainly education programs and didactic books, were mutually adjusted, with the education system as the background.

A sequence of teaching and learning deemed as traditional should be sanctioned as such by educational experience. In other words, it would be a didactic structure validated by time, rather than research, because it would have survived the ups and downs of the educational system, successfully managing the risks and overcoming the didactic-pedagogical hurdles of that system. These structures contain hints that allow teachers to separate the essential from the incidental. In a certain manner, the education sequence composed of exemplary problems that pervades mechanics courses, with its problems of blocks, inclined planes and pulleys, is comprised of school knowledge devoid of didactic risks and dilemmas. A few experienced teachers could likely evaluate the reasons why such education sequences are widely used in classrooms around the world, and perhaps provide good insights into their merits and didactic quality, even if it comes from a very personal standpoint.

A conclusion that seems to deserve emphasis in this study is that it is not enough for teachers to acknowledge and approve a proposal as innovative in itself, rather, they themselves must also translate and systematize it in terms of their own theoretical and practical experience in order to constitute a repertoire that gives them some confidence as a coauthor. The teachers in our study were capable of recognizing their own transformative role in the process of innovation. This could aid them in future innovations.

Another result of our research was the observation that teachers became aware of how, in a process of curriculum innovation, the relationships between teacher, student, and school knowledge become more evident. In other words, not only were school contents changed, but, in addition, the reciprocal responsibilities and expectations of teachers and students were transformed in the face of new knowledge. Guy Brousseau (1986) calls this set of mutual expectations a Didactic Contract. In the process of curricular content innovation, the teacher not only teaches a new subject, but also negotiates a new didactic contract. Therefore, the teacher must be willing to take certain risks. In this case, being able to manage such risks demands greater autonomy. In short, the underlying problem to be faced is how to foster greater autonomy among teachers, thereby enabling them to face the inevitable risks and dilemmas in any proposal for innovation.

Generally speaking, the fundamental problem related to the issues raised in this text can be summarized with the following question:

> How may we validate curricular innovations and introduce new scientific contents and education strategies which break away from those established by time and tradition?

Although it might seem simple, the above question is inserted in a fairly complex research scenario, since the intention is to create innovation in a much shorter time period compared to the one that stabilized school knowledge over time in traditional education. In other words, studies aimed at innovating programs and curricula, even partially, are launched with the delicate task of assuring that it is possible to teach and learn the new content proposed. In this context, the greater issue resides in the fact that we cannot wait decades for this innovation to be validated.

We believe this problem must be considered from the perspective of managing the risks and dilemmas of innovations, as previously discussed. Since the teachers are the most sensitive element in the process of innovation and see the risk of failure as a constant threat, it would be ideal to develop knowledge that granted security to the teacher in order to help her or him face and manage the risks inherent in every innovation. Studying forms of risk management could be a good way of defining such a line of work. Supported by DBR, and with the collaboration of teachers in contexts of innovation, it is possible to produce didactic knowledge that ensures the educational changes necessary for facing the challenges of modern society.

NOTES

1. Science Teacher Training for Information Society, http://crecim.uab.es/websttis/index.html
2. Project, materials, science, co-participation of five European universities.
3. Project NINA, led by the University of Amsterdam, http://www.nieuwenatuurkunde.nl/
4. http://cat.upatras.gr/
5. *Parâmetros Curriculares Nacionais para o Ensino Médio* (National Curriculum Parameters for High School).

6 Certainly, many applications of cinematography continue to be made, especially in the studies of projectiles fired by cannons and, more recently, in the perspective of rocket launching. These fields should not be considered as new theoretical products, but rather as developments of more precise models to deal with real life situations.

7 Science Teacher Training in an Information Society, http://crecim.uab.es/websttis/index.html

8 http://www.ucy.ac.cy/girep2008/

9 Book 1 of the event's proceedings defines the following themes of their work: "Instructional methods, perspectives and *innovations*, laboratory-based practices, use of ICT in science education, and other methods like use of drama in science teaching …". A search with Innovation as a key word resulted in 11 studies found. Similarly, Book 2 mentions the same topic, with about 25 works found.

10 http://ensciencias.uab.es/congreso2009/cast/6_programa.html

11 This group includes researchers from many institutes around the world. Details can be found at http://www.designbasedresearch.org/

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Maurício Pietrocola
Department of Teaching Methodology and Comparative Education
School of Education of the University of São Paulo
São Paulo-SP, Brazil

MAXWELL SIQUEIRA

2. ELEMENTARY PARTICLE PHYSICS FOR HIGH SCHOOLS

INTRODUCTION

Over the last decades, society has undergone many political, cultural, scientific, and economic changes, thereby becoming more dynamic and globalized. The consequences of these changes may be seen in the fast and efficient ways in which facts, products, information, and news arrive at almost each and every part of the planet. These processes have also made it easier for a majority of the population to have access to technological devices.

Nowadays, one cannot deny that people's daily lives have been modified by technological advances, as a result of the scientific developments which have been taking place over the last decades. Smart phones and tablets, touch-screen displays, video game systems which need no controllers, and an array of other devices which were previously only seen in science fiction movies have become commonplace.

However, when one looks at schools as a formal place for education, a place where one expects that humankind's accumulated knowledge will be passed on to new generations, one notices that few changes have taken place, especially regarding science curricula. In fact, science at school – and particularly physics – tends to be based on theories which were created before the end of the 19th century, and to ignore the last century or so of scientific development, a period which has contributed greatly to today's technologies. As a consequence, there is an increasing need to adapt and update school science curricula, particularly in the interest of information access (Terrazzan, 2007).

The teaching-learning process in the sciences holds multiple layers, from the tendencies and capacities of teachers and students, to the habits and traditions of the institutions in which science is taught, from the constantly-evolving field of science to the multiple forms of knowledge it contains. Thus, one needs to reflect on the multiple factors involved in changing school science curricula, especially physics, in order to effectively update them. A curriculum which promotes more efficient learning from students, one which includes discussions about new contents and technologies, is suitable for our time and societal demands. Such a curriculum would provide a scientific and technological education as a useful part of the culture of all citizens. Denying that change is creating a gap in students' education, which results in a pedagogical practice that is disconnected and decontextualized from their realities.

Adding modern and contemporary physics (MCP) is one possible path toward a more effective scientific education for youngsters, as well as for incorporating

M. Pietrocola & I. Gurgel (Eds.), Crossing the Border of the Traditional Science Curriculum, 23–43.

subjects that interest them, especially those comprising new technologies. Arguments for the addition of MCP in high schools have built up in the literature regarding science teaching; these aim toward innovations and updates to the physics curriculum. There is a consensus – both at the international level (Gil et al., 1987; Stannard, 1990; Kalmus, 1992; Swinbak, 1992), and at the national level (Terrazzan, 1992, 1994; Moreira & Valadares, 1998; Pinto & Zanetic, 1999; Ostermann & Moreira, 2000, 2001; Brockington, 2005; Siqueira, 2006, 2012) – that it is necessary and possible to take these new contents to classrooms.

A representative topic in MCP which effectively includes those aspects necessary to the full education of 21st-century students, one which incorporates contemporary contents and proposals and integrates the interests and conditional aspects of the learning system, may be found in the teaching of Elementary Particle Physics to high school students.

In the following sections, we will discuss the contributions which may be made by adding Elementary Particle Physics to high school classes, with reference to activities which are already part of the physics curricula in some Brazilian schools. Finally, we will discuss the main obstacles and challenges which must be overcome in order to do so.

THE CONTRIBUTIONS OF ELEMENTARY PARTICLE PHYSICS TO HIGH SCHOOL EDUCATION

It is not hard to see that the physics which is taught nowadays does not suit its time. There is a discrepancy between the teaching of that science and today's society. We teach physics knowledge from centuries ago, but we live in a modern world, surrounded by advanced technologies. Scientific developments have led to an ongoing revolution in the objects which surround us. Why not discuss the scientific concepts which contribute to that change? Elementary Particle Physics (EPP) is a topic that may be utilized to make that discussion possible.

Discussing EPP enables access to a world which is largely unexplored in most schools, the microscopic world. It enables the acquisition of higher knowledge about the structure of matter, and hence, of the world around us. Besides that, it is easy to see that this kind of content inspires great fascination in youngsters. What scientist has never been asked what quarks are? How do particle accelerators work? Questions such as these have always intrigued – and will always intrigue – students who, more often than not, receive information from the media (scientific magazines and books, newspapers, documentaries, the Internet, and other forms of media communication).

This area of physics is greatly important to modern scientific inquiry as it addresses problems which arise from the boundaries of science. The desire to know the origin of the universe and how it has evolved has led scientists to question matter and energy and their methods of transformation. Investments have been made since the beginning of the 20th century in the search to overcome the limits of knowledge, and, in particular, in the efforts to detect and understand elementary particles. The vast amounts of funds employed serve as an indication of the appeal the research in this area has to society in general. In that regard, one needs only to recall the biggest enterprise in mankind's history – the Large Hadron Collider (LHC), located at CERN.[1] The LHC is a singular enterprise case, as most people do not immediately understand why so much money was invested to build a machine that produces no tangible assets, such as energy, industrial products, etc. We believe that teaching more-contemporary physics in schools may lead students to understand why so many investments, financial and personal, are made to develop laboratory equipment such as the LHC.

Besides that, it is important to discuss the experiments which are conducted at the LHC, so that some of the information broadcast by the communication media can be demystified, such as the rumors of the possibility of the Earth being destroyed by a black hole created in the LHC. In many headlines, the collider was called a *doomsday machine*.[2]

Another important aspect of EPP in schools relates to the fact that the entities which are present in elementary particles have counterintuitive characteristics, such as reduced mass, quantum energy, virtual particles, etc. – singular aspects that define distinct behaviors of objects in the everyday world. For example, one can examine the existing mass differences of the quarks which compose protons when they are turned on (938 MeV/c^2) and when they are "separated" (approximately 12 MeV/c^2). Discussion of such cases contributes to a break with the dogma of everyday notions, and motivates engagement with counterintuitive ideas, even those which outwit us. Learning about such content in the classroom can bring students access to new worlds and ways of thinking. Conversely, discovering that those contents cannot be found in classrooms often frustrates students. Students are richly served when being stimulated to further understand complex and confounding EPP entities, or other concepts which cannot be found in their daily lives.

When they access this new microscopic world, students gain a better understanding of the structure of matter, as well as that of new technologies, and so may further comprehend some phenomena which are linked to the structures of matter and technologies. In this way, EPP gives students a new way to read the world around them; that is, a fresh way to look at nature. Furthermore, it distances them from the classical atomic models which are presented in classes, replacing them with one that is more suitable to their time, the Standard Model, which suits contemporary science.

Before further exploring the extensive educational potential of Elementary Particle Physics, it is relevant to question the contents of current curricula. Despite our now being in the 21st century, little has been changed since the 1950s in the atomic model as shown and taught in schools. It is very common to find models in textbooks that only describe three particles (protons, electrons, and neutrons, which constitute a fraction of the full set of elementary particles). The structure of matter, as described by the atomic model, is part of chemistry, physics, and even biology curricula in schools. However, such content is addressed from a historical perspective, and therefore ends up failing to reveal how rich the most current research is. Because of this approach, students end up finishing high school believing there are only three elementary particles (electrons, protons, and neutrons) and only knowing two types of forces (gravitational and electromagnetic), all as classically-described. EPP would allow teachers to present a more updated description of the atom, thus contributing to a learning that is more coherent with contemporary science; showing how developed science is, where it is going, and how it works; and pointing out the technological advances in those processes.

As a contemporary science, EPP may contribute to a more adequate, comprehensive view of scientific work by showing students how dynamic science is, how it is developed, what contributions various scientists made in order to advance a concept, and how experimenting has become both crucial and harder to accomplish. In the latter case, investments from several countries and scientists are needed to build equipment and laboratories (as in the LHC), develop theories and models, and validate them through the analysis of data from large experiments. Success involves all parties working together towards scientific development. In fact, particle physics is a very dynamic and collaborative science, always searching for new models to describe the innermost nature of matter.

Models are important elements in the daily lives of physicists. Whether it is by modeling situations or aspects of matter, models are part of the all physics knowledge. As Brockington (2005) points out, "models play an indispensable role in building scientific knowledge, and are the essence of the scientific process, through which one can conceptually apprehend reality" (p. 161). However, in spite of playing an important role in scientific theories, the process through which science builds and validates its models is hardly discussed in classrooms, let alone in textbooks. How can we wish to teach science if we do not try to discuss scientific models, one of the main scientific tools used to understand nature? The study of EPP facilitates the discussion of models, especially the Standard Model, to describe matter. It is also useful in clarifying the process through which science validates its theories, as well as that by which current science works in its attempts to describe nature.

From a more philosophical approach, EPP proposes questions which have not always permeated the development of human thought. That is so because, "*the track of the history of ideas on the constitution of matter is an important part of mankind's cultural history, and a part of human thought history itself*" (Salmeron, 2005, p. 43). In learning about this subject, students will naturally confront questions such as, "What is the universe made of?" "What is its origin?" "How has it come to be what it is today?" "What will be its end?" "Is the universe contracting or expanding?" "Will people be able to get to Mars someday?" "Is there life outside the Earth?" Such questions have made and still make human beings think about how the universe works, and impel us to try to unveil its origins and evolution. They serve as motivation for studying elementary particles and even generate a greater interest in science (particularly physics) on the parts of young people. Besides that, studying the elementary particles that are related to cosmology may contribute to the eradication of certain absurd beliefs and superstitions which are very common among youngsters (Alvarenga, 2000).

There are also some intrinsic values which elementary particles may contribute to a high school education. One may, for example, deal with meanings that are attributed to some words, like “seeing”, in physics terms. In particle physics, the studied objects are not directly “seen”, as they would be in the case of a person or a book, but rather in an indirect way, through the scattering of particles. Thus, questions, such as “Do scientists really see a particle?” and “How can they see it?”, may lead to epistemological discussions which are very rich for science teaching as well as useful in contributing to an accurate view of scientific work. The same value can be given to the word “elementary”, which brings to the surface profound questions such as: “Does elementary mean stable?” “Is the elementary as immutable as the Greeks thought?”

From this perspective, it is important to also discuss the shifts in meaning of the words “color” and “taste”, by showing that these concepts are not defined by their common meanings, but rather by that which is figuratively attributed to them. Thus, one may show that the meaning of these words is not that which is linked to our daily lives, and that the meaning of words is linked to the context in which they are inserted. This revelation leads to questions about aspects of language as related to the human being (Moreira, 1989).

All arguments mentioned so far enumerate the contributions this area may bring to science teaching, as well as to the attempt to bring a less distorted view of science to students. Classroom science will benefit greatly from fundamental concept discussions and the inclusion of discoveries such as the positron (the antiparticle of the electron), which was first theoretically proposed, and then, years later, detected. Such an approach breaks with the traditional scientific method so widespread in physics teaching; yet just such a break is necessary for progress in science and society. The discovery of that particle, the positron, for example, consequently led to the need for a new and better way to understand the concept of the vacuum, so that it could be adequately interpreted as per the new theory; that is, a paradigm shift took place, in the Kuhnian sense (Kuhn, 2003).

Aside from the inherent scientific aspects (along with the above-mentioned philosophical attributes), another possible area of inquiry that may arise in teaching EPP regards its historical and cultural aspects that may link the functioning of scientific activity and the dynamics of science to broader political and socio-cultural issues. Here, we may mention parts of the History of Physics in Brazil as examples, such as the contributions from Brazilian physicist César Lattes in the discovery and detection of one of the particles in the atomic nucleus, the pi meson. Such an approach enables students to construct a less distorted and more adequate perspective on scientific activity and the work of scientists, both in the universal advancement of science concepts and in a given country’s scientific and technological development.

Despite all the arguments mentioned above, including the great fascination particle physics may inspire in students, there are still few proposals which take

EPP into account for actual use in classrooms. This indicates the need to invest in possibilities which may, in fact, take that knowledge to high school levels. With such investment, proposals which may be taken to the classroom and which may supply data to outline more solid paths can be explored, not only in regards to including particle physics in the curricula, but also modern and contemporary physics. Either subject will lead students to acquire new knowledge over the course of attempts to get them interested in science; even if they do not follow science careers or become science teachers, they will have the chance to enjoy that knowledge area that has contributed so much to human development.

To that end, a proposal for teaching elementary particles[3] was initially prepared in 2004, and has been applied, and restructured in the years since. Nowadays, part of that proposal is used in São Paulo's state physics curriculum.

We will next mention some activities, tested in real classroom environments, which deal with the subject of elementary particles.

TRANSFORMING KNOWLEDGE TO THE CLASSROOM: THE DIDACTIC TRANSPOSITION THEORY

Knowledge that reaches the classroom goes through a transformation process, always taking into consideration the learning of this knowledge by the students. However, this adaptation of knowledge to the classroom is not merely a simplification of knowledge, because several factors that influence learning are taken into consideration, as, for example, the sequencing of learning that, in most cases, is anachronistic (although it can nonetheless contribute to a better understanding of knowledge).

The Theory of Didactic Transposition allows us to look at these transformations, because it assumes the existence of a process in which "a content of knowledge" – having been designated as knowledge for teaching – suffers, from there, a set of adaptive transformations that takes place in actually being taught. In this model, the work that transforms an object of knowledge into a teaching object is known as *didactic transposition* (Chevallard, 1991).

In the analysis of these transformations, the didactic transposition framework proposes the existence of three levels of knowledge. The first (Chevallard's [1991] terms are retained throughout), *scholarly knowledge*, where the process begins, is related to the original knowledge that is taken as a reference in the definition of a given school subject. Such knowledge is that built in the core of the scientific community. This knowledge also undergoes transformations within that community until it becomes public, when it is published in the specific scientific journals of that community. Published, the knowledge is clean, debugged, and in impersonal language, in a form which does not reveal its constructed characteristics.

Knowledge to be taught is the second level of knowledge, emergent from its first transposition (the process of transforming scholarly knowledge into knowledge to be taught). It materializes in the production of textbooks, teaching manuals for university education, school programs that target college students and teachers, and so on. Here, the knowledge is restructured in simpler language; by adjusting itself to teaching, by being "dismantled", it is reorganized again in a logical and timeless way. In this process, Chevallard (1991, p. 45) points out that knowledge to be taught sometimes contains genuine *didactic creations*, which are built from teaching needs.

In this process, as it is transformed into knowledge to be taught, scholarly knowledge undergoes a *decontextualization*, occurring via the loss of its original context, through a process that Chevallard calls *depersonalization*. Knowledge goes through a sort of "disassembly" in order to be rebuilt, allowing a new structuration and organization. Thus, this knowledge is a dogmatic configuration, ordained, cumulative, and in a way, linearized. With that, it loses the context of its origin and has a new context.

Another function of knowledge to be taught is to remove any connection with the epistemological environment in which it was created (scholarly knowledge) through a process called *desyncretization*, resulting in its being reconstituted in a new epistemological context.

> The processes of depersonalization, of desyncretization and of decontextualization, to which knowledge is subjected, strip it of its epistemological-historical context and language itself. In order to be taught, knowledge gains a new look, an ahistorical organization, a new epistemological niche, and dogmatic validity. (Alves Filho, 2000, p. 227)

Unlike the scholarly knowledge that after being legitimized by the scientific community becomes part of the larger culture, knowledge to be taught and its objects may not survive until the end of the didactic transposition process. It may become obsolete in the school context, or trivialized in its socio-cultural milieu, under pressure from groups in the noosphere, and be discarded. However, these actions share a single goal: improving teaching and learning.

The last level, *knowledge taught,* is the second transposition of knowledge, and concerns the adaptation of knowledge to didactic timing. It is at this stage that the transformation of knowledge is aimed at the sequencing of lessons. In this transformation of knowledge to the classroom, the figure of the teacher appears, with the intention to adapt the knowledge brought in textbooks (knowledge to be taught) to one that effectively reaches students. The teacher is the main character of this transposition, playing a central role at that level of knowledge. However, the teacher is not the only person involved: students and the school administration (principals, counselors, pedagogues, among others) are also the representatives and shapers of this plateau in the noosphere. This process of the transformation of knowledge to be taught into knowledge taught is called "Internal Didactic Transposition" because it occurs in the core of the school environment.

In this process, the teacher ends up suffering interference from other members of the noosphere during interactions in the school environment. This makes certain that other interests, in addition to those of teachers, are taken into consideration in the process. Because of this, a new epistemological environment is created, one that is much more unstable when compared to scholarly knowledge and knowledge to be taught. Knowledge taught is also more multiple: “Each new transposition creates a new epistemological framework (…). Within each new framework, all that is possible is done to reduce learning difficulties, dissolve them” (Joshua & Dupin, 1993, p. 201).

Each one of these levels has its own autonomous community, with its own representatives or groups. Linking these levels is the noosphere, which constitutes a sphere of action where the protagonists act in the transformation of knowledge. This sphere ends up involving people and/or institutions that influence the educational system; in other words, all of the individuals and social, economic, and political institutions that shape the transformations suffered by knowledge are considered part of the noosphere. It is inside the noosphere that the inevitable conflicts occur in the transformations of knowledge, where the various actors from different social spheres negotiate their interests and viewpoints, where the demands of society are discussed. In this environment, there are negotiations, exchanges of ideas, and conflicts, all in the quest to find solutions to the problems brought about by society. In short, “the Noosphere is the region where the thinking process of the didactic operation occurs” (Chevallard, 1991, p. 28).

However, to reach the teacher, knowledge first has to survive at the level of knowledge to be taught. For this, Chevallard (1991) highlights some evidence of relevant characteristics which knowledge must retain in order to survive as knowledge to be taught. These characteristics are:

Knowledge has to be *consensual*. Knowledge that is destined for the classroom cannot have doubts about its status of “truth”, even if that truth is momentary. Transposed knowledge must seek updates. In this case, updates are present in two modes: *Moral Actuality* is linked to the curriculum, and to the assumption that the knowledge that will be transposed has importance as recognized both by society and by parents, rather than being an obsolete form of knowledge that, for example, parents themselves could teach; *Biological Actuality* is connected directly to a subject’s own area of expertise. Transposed knowledge must be in accordance with current science, leaving obsolete concepts to be taught only in a historical perspective.

Knowledge must be *operational*. Knowledge intended for the classroom must be able to generate a sequence which includes activities, exercises, tasks, or some other sort of endeavor that has as its goal the conceptualization of knowledge. This is an important feature, because it is connected directly to evaluation. Knowledges that do not present any kind of activity conducive to learning assessment are bound to not remain long in school environments.

Knowledge must allow the existence of a *creativity didactic*. This characteristic implies the creation of learning objects that are exclusively intended for use in school activities, that is, objects that do not have similarities in scholarly knowledge, and that become in themselves creations that have a guaranteed existence only in the classroom. For example, this is the case in activities involving the association of resistors and thermometric scales.

Knowledge needs to be *therapeutic*. It has to adapt to the didactic system, that is, only knowledge that works as such stays in the school system, within the highlighted characteristics – and that which does not work is out. This characteristic can only be checked after a few years of implementation in the classroom.

In addition to these indications, Astolfi (1997), in analyzing the process of didactic transposition, stipulated some rules to describe the transformation process of scholarly knowledge into knowledge to be taught. These rules are directly linked to the relevant characteristics stipulated by Chevallard, as cited above. They are: modernizing school knowledge; updating school knowledge; articulating new knowledge with the former; transforming knowledge into exercises and problems; and making concepts more comprehensible.

In the following, we will discuss some activities based on the topic of elementary particles that have been tested in real classroom environments. These activities are didactic creations which are used as facilitators of learning for this subject, and take into account important aspects of the transformation of knowledge.

PROPOSAL OF ACTIVITIES

Activities play a fundamental role in any teaching-learning sequence, and this holds true in the case of elementary particles. The activities herein aim to provide problems to be solved by students, problems that serve as motivation for discussions on concepts in which the development of sequences is centered on student-teacher debates, in order to get students to shift their passive attitudes towards class contents.

Preparation of activities is, undoubtedly, one of the main problems to be faced when preparing any didactic sequence on MCP topics. However, by exploring possible metaphors and analogies, Brazilian researchers and teachers have been developing some activities for discussion on elementary particle concepts, which are described below:

Proposed by Siqueira (2006), the activity called Analyzing radiographies (*Analisando as radiografias*) (Figure 1) served to introduce the sequence of particles. It aims to lead students to understand the production process of X-rays, radiographies, and differences in the shades which are found in them, as a consequence of the absorption by different materials of distinct densities. To that end, we try to have students understand the nature of X-rays – how they were discovered, their consequences in the scientific community – and, further, to get them to search for additional information on the nature and structure of matter, in order to better understand X-rays.

In this activity, students are invited to analyze radiographies in order to pinpoint some peculiarities, such as differences in shades, sharpness, edge contrasts, body parts, prosthetics, cracked bones, and others. Afterwards, questions are raised by the teacher, in order to guide the discussion, such as: “Which radiography called your attention the most?” “Why?” “Why are there clearer and darker regions?” “Why are some radiographies sharper than others?” “How are radiographies produced?”

Figure 1. Students observing radiographs

Such questions serve as a motivation to start a discussion about X-rays and radiographies which allows for inquiry around how X-rays were discovered, their consequences and applications, as well as their nature, the "creation", detection, and absorption processes by different materials, etc. In order to make the whole discussion formal, teachers and students may refer to the text, "Seeing through skin: the discovery of X-rays" ("*Vendo através da pele: a descoberta dos raios X*").[4]

To finish the discussion, the activity is complemented with an analogy – *X-rays with photographic paper* (*Raio X com papel fotográfico*). Several opaque, translucent, or transparent objects of any shape are placed on a light-sensitive sheet of photographic paper (Figure 2). After remaining next to a light source for approximately five minutes, the objects are taken off, and the marks left by them can be observed (Figure 3). Then, two questions are asked: "How well can you distinguish the shapes of the objects?" "Are there differences regarding sharpness (shades) in the marks left by the shapes on the photographic paper?"

Figure 2. Photographic paper with opaque objects

Figure 3. Photographic paper after exposure to light

This second part of the activity aims to draw an analogy with the production of radiographies, with the light source that sensitizes the paper analogous to the X-ray source; and the photographic paper, which is light-sensitive, analogous to the radiography itself. Thus, we seek to visualize and materialize the discussion held in the first part of our activity, aiming to lead students to better comprehend the main aspects of X-ray and radiography production. This is believed to be a format which motivates discussion, as radiographies and X-rays are objects that are relatively close to the daily lives of students. This familiarity lends significance to the problem which is proposed in the activity, as students wish to discuss their answers and conclusions.

This discussion on the discovery of X-rays and radioactivity emerges as crucial in unveiling the structure of matter – the atom. Although other investigations have contributed to discovering the structure of the atom, studies of X-rays and radioactivity were the ones that opened the doors to the development of new areas in physics, such as nuclear, atomic, and, particularly, particle physics. As a content for high schools, the subject is believed to lead students to better understand those physical objects present in their daily lives.

A second activity, found in Siqueira (2006), is Rutherford Scattering (*Espalhamento Rutherford*),[5] which is an analogy to the experiment which was conducted by Ernest Rutherford to propose the atomic nucleus. This activity is initially aimed at leading students to discuss how to "see" an object that cannot be seen by the naked eye, due to its microscopic size, as in the cases of atoms and atomic nuclei. The idea is that Rutherford's method (scattering with alpha particles), which is commonly used in nuclear, atomic, and elementary particle physics, can be materialized for the classroom. It is important and useful in this activity to show that the concept of scattering is closer to our daily lives than one might imagine. In fact, the phenomenon of scattering is actually in use all of the time, in rendering objects visible: The process consists of light scattering when it hits an object, this scattering is in turn detected by the eyes, which are capable of receiving visible light.

In this activity, several wooden boards are used, with geometric shapes made of Styrofoam glued under them. Each board corresponds to a shape, which remains under the table so it cannot be seen. From that point on, the boards begin to be probed by releasing marbles, in order to determine the shapes that are glued beneath the boards (Figure 4). In order to do that, the reflection principle is taken into account (the angle of incidence is equal to the angle of reflection), by tracing the path of marbles at incidence and at reflection (Figure 5). With those data, it is possible to start to outline the shapes which are underneath the boards, outlines which become “sharper” after a certain number of incidences.

Figure 4. Student rolling marbles in order to mark their paths and then analyze them

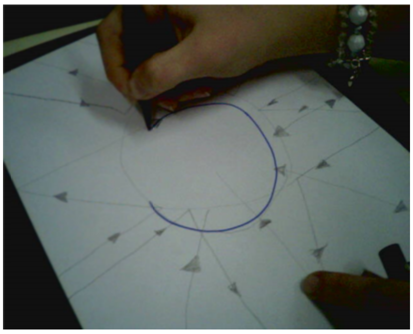

Figure 5. Student analyzing trajectories and trying to trace the resulting geometric shape

In order to outline the shape, a piece of paper is placed on the wooden lid, and the paths of the marbles are recorded. Next, the collected information is analyzed in order to determine the effective shape of the object. The idea is to have more than one board, so the “true” shape of the object hidden under the board can be compared among the various groups.

This activity is followed by a script, which proposes questions to designed to enhance the activity: “How can you determine the size and shape of the object?”

"How could you know whether the figures have details in their shapes, which are small if compared to the marble sizes?" "How can you confirm your conclusions without looking at the objects?"

With such questions, a discussion is started on activity goals, in an effort to get students to understand how atomic investigations are carried out, how the development of particle accelerators allowed further investigation of the atom, and the particles themselves. This activity is focused on answering the last question, wherein we have an opportunity to discuss the idea of models, and to give examples of the atomic models used in high school chemistry and physics textbooks.

Through the discussion of atomic models, it is possible to discuss the use of models in science and the role models play in theories. When one is not sure about the real shape of the object under investigation, models are resorted to in order to have an approximate view of the studied object or phenomenon. This activity serves as a metaphor for what happens in scientific research, and it reveals a fundamental facet of the teaching-learning process through which young students begin, in the classroom and in their own discussions, to understand scientific work. The activity also allows discussing model validation processes, thus creating a classroom environment which is analogous to a genuine scientific debate. Classroom consensus is reached through debates which are based on ideas, arguments, and collected information. In this way, these discussions end up reflecting actual scientific work, as well as how science evolves by changing its models and theories, in the attempt to get closer and closer to reality.

Another activity proposed by Siqueira (2006) is called "Categorizing particles" ("*Categorizando partículas*"). The central idea of this activity is for students to start understanding that there are characteristics or properties which allow the grouping of particles into families, thereby creating order.

In the activity, students get an array of little balls (several colors, sizes, and materials), and they are asked to separate them into groups, as per a property (or the properties) by which they see fit to group them. After the activity is finished, the criteria which are used by physicists to separate elementary particles into quarks, leptons, and bosons are discussed.

An activity proposed by Silva and Siqueira (2013b) aims to discuss the working principle of particle accelerators, especially circular ones. In this activity, the following materials are used: a 180-mm diameter circular iron board (paint can lid), 11 10-mm diameter steel balls, and 5 10-mm diameter round neodymium magnets. The magnets are secured to the platform in an equidistant way, and two balls are placed in front of each magnet (Figure 6). A single ball receives an initial push, which will initiate the circular motion.

Through the assembly of the materials and the experiment itself, it is possible to discuss several concepts which are present in particle accelerators, drawing an analogy with the LHC (Large Hadron Collider). In our experiment, the balls simulate the particles which are accelerated without the action of an external force in the system, through the magnetic force of magnets. When observing the motion continuity of particles at increasing speeds, it is possible to draw an analogy with particles from real accelerators, such as the LHC, where particles reach 11,000 revolutions per second. Nonetheless, in those real accelerators, especially the circular ones, magnetic induction is mainly intended to guide particles. In the experiment proposed, magnetic induction, besides guiding them, also plays the role of accelerating the balls, whereas, in real accelerators, what accelerates particles is the difference in potential. It is important to point out that there are certain limitations in our analogy, such as the balls representing particles and the function of the magnetic field in both cases.

Figure 6. Particle accelerator assembly

Silva and Siqueira (2013a) also propose an activity which uses crosswords to support discussion of the primordial elements that constitute matter and the evolution of atomic models. The questions and tips in this activity are developed from the texts prepared by Siqueira (2006) for teaching Elementary Particle Physics, and they can also be found in a textbook (Pietrocola et al., 2011). An example of a crossword that was created by the authors follows:

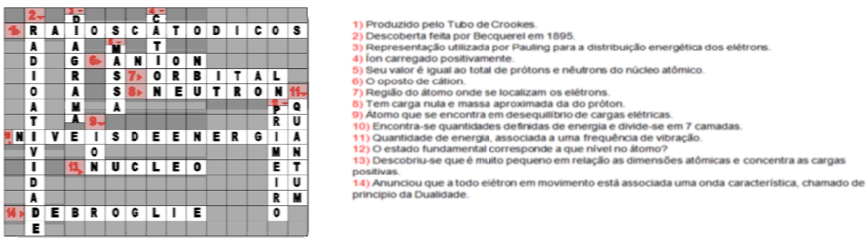

Figure 7. Particle crossword

In addition to the previously described activities, a series of other activities called Learning Situations[6] (in development since 2008 and also involving elementary particles) makes up the regular curriculum of the public schools in the State of São Paulo in Brazil. The first of these deals with the development of science and the importance of Brazil's participation in finding the solution to a question about the stability of the atomic nucleus, a discussion that occurred during the decade between 1930 and 1940. The activity was based on research developed by Santos Neto (2007).

The activity is developed in two steps. The first aims at showing to students that Brazilians have played important roles in the development of science, contributing significantly to advances in scientific theories. Thus, students are invited to read part of the text (Figure 8) and suggest a title for the report. After that, the titles given by each student and their meanings are discussed. The second part delves into the importance of Lattes' discovery for Elementary Particle Physics, discussing the role of the pi meson in the theory of atomic nucleus stability and the consolidation of its description. The discussion held in this activity aims to recognize Brazil's participation in the international field of science and to grasp aspects relevant to the process of creation of science in a historical perspective.

SÃO PAULO — QUARTA-F

Os estudos de Cesar

na Inglaterra e

Declarações do jovem cientista brasileiro – Em

Radicais

Deverão ser substituíd
dual, segundo revelaçõ

Obtem um jovem cientista brasileir
a produção artificial do "meson"

Considerada uma das mais fantasticas realizações da ciencia atomica — Como se referem à descoberta de Cesar Lattes os membros da Comissão de Energia Atomica dos Estados Unidos — A importancia do "meson" para os estudos de energia atomica — Quem é o jovem cientista radicado em São Paulo que assim galga os degraus da celebridade

Tem despertado enorme interesse nos circulos cientificos brasileiros e mundiais a recente descoberta do jovem fisico brasileiro Cesar Lattes.

Trata-se da produção artificial do "Meson", conseguida nos laboratorios da Universidade de Berkley, nos Estados Unidos, onde se encontra o jovem patricio gosando as vantagens de uma bolsa de estudos. A descoberta foi anunciada pelo sr. Ernest Lawrence, diretor do Departamento de Pesquisas da Comissão de Energia Atomica dos Estados Unidos como sendo "uma das mais fantasticas realizações da ciencia atomica", tendo acrescentado o sr. James B. Fisk, membro da mencionada Comissão que a descoberta de Lattes abrirá novos horizontes nas pesquisas de energia atomica, sendo de esperar-se revelações maravilhosas para muito breve.

IMPORTANCIA DO "MESON"

O "meson" é uma particula atomica intermediaria entre o proton e o electron e de grande importancia como componente nuclear. Sua existencia foi prevista pelo fisico japonês Yukawa, que, estudando a natureza das forças nucleares e a explicação da teoria da relatividade, chegou à conclusão de que devia haver uma nova particula, cuja massa correspondia a cerca de duzentas vezes à massa do electron, particula essa necessaria à interpretação dos resultados experimentais relativos à desintegração nuclear.

Enquanto os protons e os electrons já eram obtidos nos Laboratorios de Fisica Nuclear, tendo sido objeto de pesquisas intensas desde as famosas experiencias de J. J. Thomson, Rutherford e outros grandes fisicos, o "meson", mesmo depois de descoberto nos Raios Cosmicos, não havia sido obtido experimentalmente;

Cesar Lattes, o jovem cientista brasileiro que acaba de surpreender o mundo produzindo artificialmente o "meson"

Os trabalhos realizados por Cesar Lattes, em Bristol, com chapas fotograficas sobre Raios Cosmicos, permitiram-lhe descobrir a existencia de dois mesões de massa respectivamente de

(Continua na 2.a pagina).

Figure 8. Clipping of a story about César Lattes' discovery from a newspaper of the time

Brazil's involvement, through César Lattes (in collaboration with a group in England), in detecting the pi meson by using experimental studies of cosmic rays occurred in 1947. In the following year, Lattes was able to detect the same particle in the laboratory. The importance of this discovery to science is discussed with students using the reportage of that time, as conveyed by the newspaper *Folha da Noite*.

Another proposed activity deals with the process of detecting particles in bubble chambers. From the known trajectories of some particles (Figure 9), we investigate, by comparison, the trajectories of unknown particles, which are originated from reactions or decays (Figure 10). This process, while respecting its limitations, is analogous to the procedure that scientists perform to identify particles that leave their traces in bubble chambers or clouds.

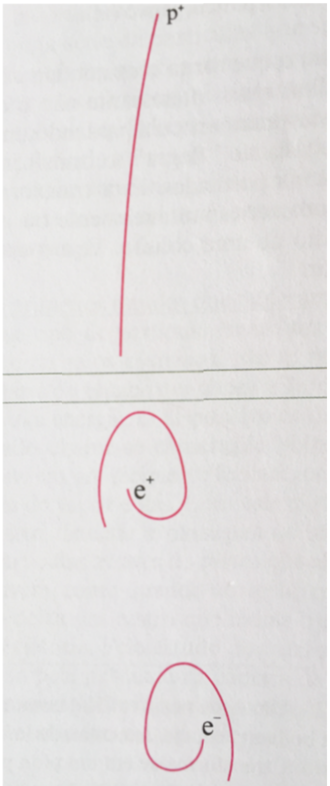

Figure 9. Track left by a proton (p^+), an electron (e^-) and a positron (e^+) going through a bubble chamber

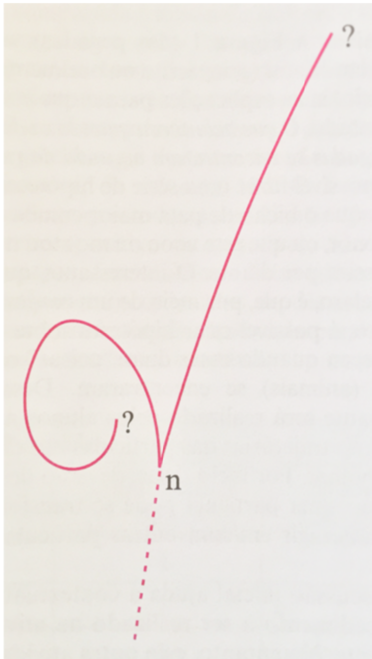

Figure 10. Track for identification of unknown particles

In this way, students observe the reaction or decay and initiate the comparison, by means of reference particles, seeking to determine which particles participate in the process. After this investigation, discussion about bubble chambers initiates a consideration of the reasons why some trajectories are presented in the form of curves and some as spirals, while others appear straight.

One can see that the development of this activity facilitates the discussion of some relevant aspects that characterize particles, such as their load, mass, and stability. In addition, it allows teachers to demonstrate aspects of the process of detecting subatomic particles which, although not directly viewed, can be identified through their passage in the bubble chamber or clouds. This is important to understanding the construction of ideas in science, especially when dealing with the physics of elementary particles.

OBSTACLES AND CHALLENGES

Adding EPP in Brazilian schools involves overcoming obstacles and challenges, mainly because of its non-intuitive and abstract aspects. The obstacles and challenges found in the literature include shortages of good quality textbooks, deficits in teacher backgrounds, the mathematical formality used in EPP contents, and the lack of learning activities for students.

The lack of materials for teachers is a challenge which has been pointed out by physics teaching professionals for some time. Although there are several source materials available for EPP,[7] most of them cannot be immediately used in the classroom, as they need to be transformed in order to be used for that context. In addition, although the textbooks which were approved by 2015's *Programa Nacional do Livro Didático (*or PNLD, Brazil's National Textbook Program) deal with particle physics, they still, with rare exceptions, do so in the classical way. A quick analysis of most textbooks may reveal that EPP is still taught in the traditional way, by summarizing all knowledge of particles in tables which seem to condense all the richness of that topic. In fact, what such textbooks do is sell something old for something new.

Another relevant aspect is the background of physics teachers, since adding particle physics into the curricula without the involvement of properly qualified professionals is unthinkable (Siqueira & Pietrocola, 2012). In Brazil, physics courses led by licensed teachers hardly ever cover EPP; when they do, they are usually taught by professors/researchers in areas unrelated to education, and rely on older textbooks, such as Eisberg and Resnick (1994). Besides that, the latter theoretical disciplines are not related to pedagogical disciplines, never mind incorporating supervised internships. This renders EPP even less accessible for high schools, as, even though there are disciplines related to such topics, they do not provide enough subsidies for future teachers to cover it in classrooms; that is, this topic lacks the operational aspect for high school education (Siqueira, 2012). In other words, it is not enough for teachers to "know", they also need the know-how (Carvalho & Gil-Perez, 2001).

Another already-identified problem regards the mastery of mathematical formalism which is needed to deal with the topic. Many times, teachers, due to their background, see the physics taught in high schools as a simplified version of academic physics, mainly in regards to mathematical formalism; that is, the difference between levels of physics at high schools and universities is framed by teachers as just a matter of degrees of difficulty, with mathematics being the clearest indicator (Siqueira, 2012). However, dealing with fundamental EPP aspects and concepts through a conceptual and phenomenological approach is believed to be possible, allowing for conceptual discussions and guiding learning along qualitative aspects of the topic. That strategy seems to have great potential, as qualitative and phenomenological discussions enable the main concepts and aspects related to science to be discussed, without the need for broad mathematical knowledge on the part of students.

Nevertheless, the most critical point which is presented in any proposal to include MCP, which is no different for particle physics, is the matter of teaching activities. The phenomena on which the theories comprising EPP are based belong to a world not easily accessible in day-to-day life. Typical didactic experiments cannot be used to demonstrate such subject matter; rather, most EPP experiments are highly complex and very expensive, not being suitable for the reality of our schools. However, with a certain amount of didactic creativity, low-cost activities can be adapted which may function to improve students' learning through a better understanding of course contents. This will enable more dynamic classes, stimulating discussions among students, and thereby helping students to become less passive and to actively take part in building their own knowledge.

FINAL CONSIDERATIONS

The experience of developing and monitoring teachers in implementing activities and proposals for teaching elementary particle physics revealed that certain challenges and obstacles are inherent in any proposal for teaching that makes innovations to material already enshrined by tradition. Nonetheless, these can be overcome through the joint development of teaching materials and teacher education, especially when teachers participate directly in developing the materials for the teaching-learning sequence. These latter are the foundations for success that can be highlighted for the innovative activities presented here.

In fact, the relative success of activities developed in the classroom depends primarily upon the direct involvement of high school teachers in the development, implementation, evaluation, and restructuring of those activities. This participation leads teachers to identify with the material and thus creates greater personal engagement.

> The teacher is a key element in education transformation processes, since any innovation process is only possible if it involves the teacher directly, because changes in education depend on what they do in their classes. (Flores & Flores, 1998, p. 97)

At this point, after several years of research and implementation of our proposal on EPP and its inclusion in the São Paulo state curriculum, we may conclude that it is possible to teach such contents in Brazil's high school context. In the same way that there are no clear limits for human intelligence, which is always engaged in its efforts to understand the world, the same conviction should exist vis-à-vis the possibilities for taking that understanding to all students, thus contributing to an improvement in the scientific culture of those individuals and of society writ large.

Even so, there remains a very clear and specific path on how to insert this and other topics of modern and contemporary physics in the classroom. We have wagered successfully upon the methodological referential of Teaching-Learning Sequences (Méheut & Psillos, 2004), which has significantly contributed to the success of our proposals.

NOTES

[1] A French abbreviation for the European Organization for Nuclear Research, located on the border between France and Switzerland (Geneva).

[2] http://veja.abril.com.br/090408/p_086.shtml

[3] The complete proposal material can be found on NuPIC's website: http://www.nupic.fe.usp.br/

[4] That text is part of the didactic sequence proposal on elementary particles, and it can be found in Siqueira (2006), or on NuPIC's website: http://www.nupic.fe.usp.br/

[5] Further details on the preparation of the activity may be obtained in Siqueira and Pietrocola, 2010.

[6] These Learning Situations are available in *Cadernos de Orientação do professor de Física* – 3 ano – caderno 4. São Paulo: Secretaria de Educação do Estado de São Paulo, 2008, Vol. 1. 46 pp.

[7] In a study by Siqueira and Pietrocola (2005), a survey was conducted on elementary particles subjects which are accessible to teachers and that may be used by them to start including that topic in classes.

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Maxwell Siqueira
Exact and Technological Sciences Department
University State of Santa Cruz –UESC
Brazil

MÁRLON PESSANHA AND MAURÍCIO PIETROCOLA

3. PARTICLE ACCELERATORS AND DIDACTIC OBSTACLES

A Teaching and Learning Experience in São Paulo and Cataluña

INTRODUCTION

After a few decades in which educators and researchers in the field of physics education discussed the inclusion of topics from modern and contemporary physics (MCP) in high school, a consensus has emerged regarding the need for that insertion (Ostermann & Moreira, 2004).

The list of the main reasons to justify such insertion includes the necessity of student contact, in schools, with science as it is currently practiced. Contemporary scientific production – as disclosed on the Internet, in TV news, newspapers, magazines, and other places – is not necessarily handled with the necessary scientific precision. Therefore, students hear and read about quantum physics, relativity, black holes, and particle accelerators, among other topics, in different spaces, but not at school.

Above all, particle accelerators stand out in modern science as being crucial in the areas of elementary particle physics (EPP) and nuclear physics, without which such areas would not have developed as much as they have (Das & Ferbel, 2003, pp. 183–184). A school curriculum adequate for the contemplation of topics related to science as it is practiced nowadays would inevitably include such topics as EPP and nuclear physics, as well as the equipment involved in those areas.

In fact, in the last few years, the official high school curricula of states, provinces, and autonomous communities of different countries have been undergoing innovations that, among other changes, include topics of MCP. For example, in Brazil, the official curriculum of São Paulo State was updated in the late 2000s, when new topics were incorporated in the discipline of high school physics related to:

> Quantum Physics and the Structure of Matter, such as the properties and organization of matter; the atom and the emission and absorption of radiation; the atomic nucleus and radioactivity; elementary particles, and electronics. (São Paulo, 2008, pp. 49–60)

In another example, in Spain, the official curriculum of the Autonomous Community of Cataluña, also published in the late 2000s, foresees, more specifically, that EPP must be addressed in the post-obligatory discipline of high

M. Pietrocola & I. Gurgel (Eds.), Crossing the Border of the Traditional Science Curriculum, 45–59.

school physics,[1] and recognizes the need for the investigative instruments of this field, such as accelerators and detectors (Catalunya, 2008, pp. 59263–59277).

With the structure of matter and elementary particles being included in the curriculum, a challenge that emerges has to do with planning suitable situations in which to teach such subjects: the study of the structure of matter and its equipment involve both phenomena and entities not included in the direct perception of the daily world; moreover, they become reality and are accessible only through techniques developed in a highly rational manner. In other words, the challenge in teaching this topic is to provide conditions that allow teachers and students to overcome the difficulties in actual perception of the phenomena and entities that are targets of the study.

In this chapter, we discuss the experience of a course about the structure of matter and particle accelerators implemented with students from São Paulo State (Brazil) and students from the Autonomous Community of Cataluña (Spain). In the following, we present a reflection on the nature of the scientific knowledge involved in dealing with this topic and describe how such understanding guided the planning of the course. Next, we will present a reflection on the didactic actions of the teachers, in which we verify how inadequate or scarcely-adequate didactic choices influenced the learning process of the students, either reinforcing or actually producing mistaken conceptions regarding the nature of the subatomic world.

A NEW SCIENCE OF PHENOMENOTECHNICAL KNOWLEDGE

Before we present the course on particle accelerators and report on some didactic obstacles involved in its implementation, we believe it is important to emphasize something that was especially relevant in its planning: our perspective on the nature of MCP knowledge. This view allowed us a clearer understanding of the relationships between the scientific knowledge involved in the study of the structure of matter and the techniques used in particle accelerators, thereby allowing us to better define our activities.

As a basis for our reflections, we used some ideas of the French science philosopher Gaston Bachelard, who was a contemporary of the emergence of the new physics that started in the late 19th and early 20th centuries. When Bachelard (1975) analyzed the science that was practiced at his time, he stated that modern physics was no longer engaged in the reproduction of a given reality, but that in fact new realities were being invented with the use of new equipment. He claimed that knowledge was being built based not on direct observation or on the instrumentation of the natural phenomena, but on the creation of phenomena that took place inside the equipment. This meant that, on the one hand, knowledge was still being built based on a methodological accuracy characteristic of previous centuries, but, on the other hand, the phenomena being studied were those created within the science equipment itself, rather than phenomena perceived in the daily world.

Subatomic particles or the corpuscular behavior of light are not directly and naturally accessible to the senses, but they can be built as a technically accessible reality. The equipment used in modern science, mainly in the atomic and subatomic worlds, allows us to indirectly reach a phenomenon both rationally predicted and technically built.

The result is a doubly-built scientific reality, both by technique and by theory, by experimentation and by rationalization. Thus, in the study of the subatomic world one no longer deals with a "natural reality" provided to the senses, that is, with a phenomenon-like reality. On the contrary, one deals with the product of techniques, that is, with a phenomenotechnical reality (Bachelard, 1975; Rheinberger, 2005).

Particle accelerators are a flagrant example of phenomenotechnique, but many other types of equipment and experiments deal with a reality that cannot be noticed directly by the senses, but that is both accessible and built through technique. A historically-relevant example is Geiger and Marsden's experiment of scattering alpha particles, which led Rutherford to propose a new atomic model in the early 20th century. In this historical experiment, scattering took place through the following technique: alpha particles, invisible to the naked eye, were scattered when they interacted with an obstacle (gold foil), and the scattering became evident when they interacted with zinc sulfide screens.

In short, when we define the knowledge of the subatomic world as being phenomenotechnical, we take two important issues for granted, namely: (1) that this knowledge is built upon a reality that is also built, a reality which is inaccessible in the daily world and that, therefore, breaks with the immediate; (2) that in order to understand the concepts deriving from modern and contemporary theories, it is relevant to understand the techniques themselves as applied knowledge.

Thus, since the knowledge built upon the subatomic world and elementary particles involves a phenomenotechnical reality, in the course as planned (and described in the next section), we deal with the topic of the structure of matter by debating technique, by investigating the historical experiments that helped develop this area, and, finally, by discussing particle accelerators.

THE COURSE ON PARTICLE ACCELERATORS

A significant amount of the scientific knowledge about the atomic and subatomic worlds emerged from experimental methods based on the technique of inference by trajectories, in which, among other things, one verifies the consequences of the interaction between macroscopic particles or objects with known properties with something that one wishes to know. Throughout the 20th century, this technique allowed the discovery of several properties both of the atom and of subatomic particles.

When this course was designed, we developed activities that investigated this technique. In some cases, computer simulations were used to represent the experiments and interactions in which the technique was explored. The activities of the course were conceived and organized in an interconnected manner, and they were designed in such a way as to allow a gradual building of understanding about particle accelerators.

In general, as emerging from discussion of both concepts and technique, the goal of the course was for the students to understand what particle accelerators do and how they work. Therefore, the relationship among particle accelerators, the technique used, and the physical knowledge that these generate made up a conceptual model (Greca & Moreira, 2000) that the students were expected to gradually build.

The course was thus designed while taking the idea of phenomenotechnique into consideration, and incorporating the gradual building of technical and scientific knowledge. Such elements guided our didactic design and, therefore, played a role in what some authors (Méheut & Psillos, 2004) define as design principles.

In Table 1, the basic structure of the course is presented in detail, indicating each main stage (identified by Roman numerals) and its respective activities (identified by Arabic numerals).

Taking as a starting point some ideas that we considered to be part of the previous conceptions[2] of the students, the activities were designed in such a way as to allow a layered building of the conceptual elements necessary for discussions about what particle accelerators do and how they work.

Each of the activities, interconnected among themselves mainly by reference to technique, allowed us to bring to the surface a set of conceptual elements that would be useful in understanding particle accelerators. At the same time, these activities served the need to discuss or to deepen other contents foreseen in the curricula both of São Paulo and Cataluña. One example arose in the study of atomic models (Stage III of the course), foreseen in both curricula, which allowed us to deal with the scattering technique present in the accelerators and involved conceptual elements, such as the electric interaction among subatomic particles.

By the end of the course, the students were expected to have developed a sense of the structure of the atom and its particles (subatomic, including the sub-nuclear ones), to recognize electric and nuclear interactions (strong force and weak force), and to understand how particle accelerators work, as well as their role in revealing and validating new knowledge about the structure of matter. Such elements were part of the target conceptual model that the students were expected to build during the course.

Figure 1 presents a scheme that indicates the main ideas that comprise the expected/target conceptual model, and the partial models that were expected to be learned during the course. As can be seen, several conceptual elements were inserted during the course; these were connected with the building of the target conceptual model that describes how particle accelerators work and their use in the study of the structure of matter. The numbering from 1 to 9 in this figure is the same that identifies the activities described in Table 1.

Table 1. Basic structure of the course "From Thomson to Particle Accelerators"

Stages	Activities
I. Presentation and Motivation (25 minutes)	After a brief introduction to the course, a motivation activity begins that seeks to make the students think about the importance of studying the insides of matter (1). The activity reports on research involving X-Rays obtained in a particle accelerator and used to investigate better drugs to treat coronary diseases. The use of X-Rays to determine the inside structure of macroscopic objects or parts of the human body is also discussed (2).
II. Analogical Experiment (45 minutes)	Based on an analogical experiment[3] (3), a demonstration of the technique often used to study the structure of matter and particle accelerators, which allows to us obtain information about an unknown or hidden object based on its interaction with an object whose properties are known, is attempted. In the analogical experiment, having access only to marbles, the students must conceive of an experimental method to find out the shape, size, and details of a geometric object hidden under a wooden surface.
III.Structure of the Atom (100 minutes)	Based on the technique introduced in the previous activity, Thomson's atomic model (4) is discussed, as well as its transformation since the historical experiment conducted by Geiger-Marsden (5), and the adequacy of an atomic model with a positive nucleus, as is the case in Rutherford's atomic model (6). This stage uses computer resources that allow simulation of both the historical experiment and the electric interactions between charged particles and the atomic nucleus.[4]
IV. The Technique (25 minutes)	In this activity, based on proposed questions and using a computer simulation[5], students attempt to compare the technique used both in their analogical experiment and in Geiger-Marsden's historical experiment (7). The emphasis in the discussion of the technique and its use is on studying the insides of matter, which serves as a bridge for later discussion about particle accelerators.
V. Particle Accelerators (25 minutes)	This last stage includes a debate about what particle accelerators are and how they work (8). In addition, there is a brief treatment of the Large Hadron Collider (LHC) and an example is given of a particle accelerator located near the region where the course takes place: in Cataluña, the ALBA Synchrotron was mentioned, and, in São Paulo, the PELLETRON of the University of São Paulo (9).

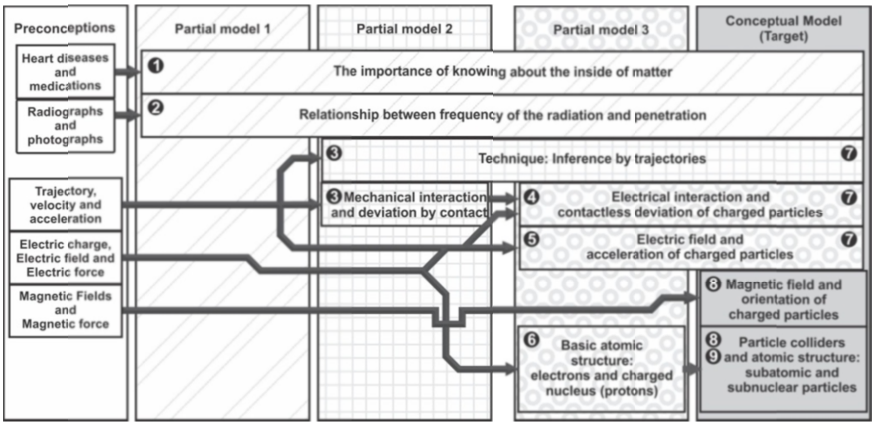

Figure 1. Scheme representing both the partial and final conceptual models (target)

THE IMPLEMENTATION OF THE COURSE AND SOME LEARNING OBSTACLES

There were six implementations of the course, with four implementations being with students from Cataluña (Spain) and two implementations with students from São Paulo State (Brazil).

The implementations revealed that students had different difficulties in understanding the concepts, some of which were related to the fact that the phenomena and entities studied were not directly amenable to the senses and, in many cases, they were counterintuitive, which broke with students' daily experience.

In both contexts, we noticed that students often interpreted virtual experiments and theoretical contents according to phenomena that involved macroscopic objects. Thus, the movement, trajectories, collisions, and penetration capacities of subatomic particles tended to be explained by students in the same way as the dynamics of objects that were accessible to the human senses.

Such attachment to what is easily perceptible and its use in trying to interpret what is new was an obstacle to building knowledge. This kind of obstacle, which is intrinsic to the act of knowing itself, is often defined as an epistemological obstacle. The science philosopher Bachelard (2002) was the first to emphasize this kind of obstacle, in his analysis of the historical path of science in the early decades of the 20th century.

The French educator Guy Brousseau (2002), in his theory of didactic situations, defined the epistemological obstacle as a kind of learning obstacle. Brousseau also defines other kinds of obstacles that act in didactic situations, including didactic obstacles. Such obstacles have to do with the didactic choices made by teachers in the class planning – or even during the lesson itself – that are either inadequate or scarcely adequate.

During the design and the implementation of the course, we relied on the participation of high school teachers, who were in charge of defining many of the didactic approaches and pedagogical resources that would be used in course activities. In our analyses, we noticed that some of those didactic choices in fact acted as didactic obstacles, which reinforced or even led to mistaken conceptions about the subatomic world. Next, we will describe three of those situations:

Situation 1 – Scarcely Adequate Images and Texts

One of the stages of the course involved a prediction (activity 4 of Figure 1) followed by a virtual experiment using a computer simulation of Geiger and Marsden's historical experiment (activity 5 of Figure 1). In the activity, the students had to predict what was expected when positively charged particles (alpha particles) were cast against an atom, according to Thomson's model.

When the students made the prediction, they were asked to plot, on paper, the trajectories of the charged particles. With this part of the activity, it was expected that the students would be able to recognize the inadequacy of Thomson's atomic model during the virtual experiment and express the need to elaborate a new one.

However, when the course was implemented for the second time, with students from Cataluña, many of them indicated in their predictions a trajectory that was different from the one expected. Instead of plotting the trajectories of the particles with these going through the atom, which was expected for Thomson's atom, these students indicated a collision between the particles and the atom's "surface". An example is shown in Figure 2.

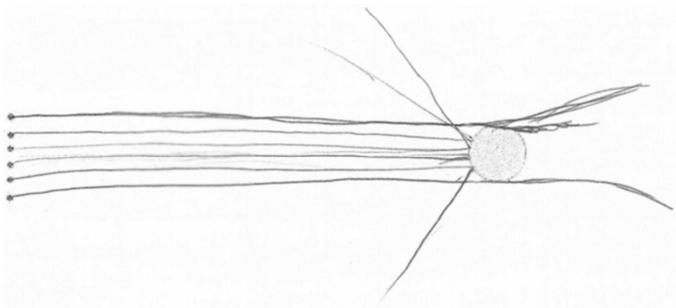

Figure 2. Example of a drawing made by one of the students

As can be seen, the drawing of the trajectories indicates a collision in which the alpha particles touch a would-be surface of Thomson's atom, not going through it and, thereby, undergoing a major deviation. With this flawed prediction, the students would not be able to recognize the inadequacy of Thomson's model in the later activity with the simulation of Geiger and Marsden's historical experiment.

During the dialogues that took place in the classroom, the students were asked why they described the trajectories of the particles in that way. Some of them stated that the atom was solid and impenetrable and, in order defend this notion, they resorted to the idea of mass exposed in the statement used in the available material itself:

> The atoms of the elements consist of a certain number of negatively charged corpuscles, immersed in a sphere with positive charge and mass.[6]

This statement did not present incorrect information, and Thomson's atom could actually be defined as presented. However, its reference to mass led the students to a mistaken perception of a solidity to the atom that would cause deviations by means of collision. Since the description of the atom as something that has mass was not necessary in order to understand the interaction that took place between the alpha particles and the atom, the reference to mass was deemed scarcely adequate, since it facilitated the existence of naïve perceptions in students' understandings of Thomson's atom.

In the same implementation, some students also referred to a presumed surface of Thomson's atom when they justified the collisions between the alpha particles and the atom. When the students were asked about that presumed atomic surface, their explanations relied on two images available in the material itself: the image on which they should draw the trajectories (the grey circle present in Figure 2), and the image of Thomson's atom shown in Figure 3.

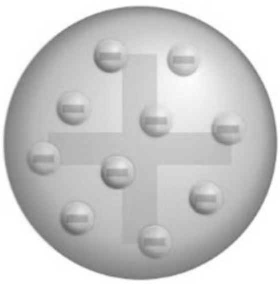

Figure 3. Representation of Thomson's atom used in the 1st implementation of the course

Therefore, not only was part of the text used scarcely adequate, but the visual representations of Thomson's atom which were used suggested the idea of collision. Both the text and the image for Thomson's atom were changed for the later implementations of the course. The text that described Thomson's atom was changed to no longer mention mass. In turn, the images used to represent Thomson's atom were replaced by representations that did not give a false idea of surface, as can be seen in Figure 4.

Figure 4. Representation of Thomson's atom used since the 2nd implementation of the course

Situation 2 – Inadequacy in the Lack of Metaphor Deconstruction

In the three last implementations of the course in Cataluña, the participating teachers often used a metaphor in their explanations: Thomson's atom was like a cloud, and the alpha particles could cross it easily.

In many instances when this metaphor was used, it was not specified which elements of the comparison should be taken into account, leaving that interpretation to the students. Therefore, students could potentially list several characteristics of a cloud that would not apply to Thomson's atom, leading to a mistaken understanding thereof. One example of this took place during the 2nd implementation of the course, transcribed next:

Teacher 3: Yes. Imagine the atom as a cloud. It is similar to a cloud.
Student 8: What do you mean a cloud? Like a fluid?
Teacher 3: Yes. Like a fluid, which can be crossed.
Student 8: Does the atom deform?
Teacher 3: Deform? How?
Student 8: When an object moves through the air, in a fluid … If it is like a fluid, then the atom deforms. The object in the air makes … makes … tornados, small tornados.
Teacher 3: No. It crosses … Are you talking about vortices?
Student 8: Yes, I think so.
Teacher 3: No. Imagine that the atom, Thomson's atom, is like a cloud, like a fluid, in the sense that it can cross it. The atom is not a fluid, it crosses as if it was in a fluid. For example, balls thrown into the air. Thomson's atom is a … see the definition. Where is it? Here. [He points to the description of Thomson's atom available in the activity's

guide.] It says that it is a positive sphere with negative charges, ok? The atom is a sphere that can be penetrated by the alpha particle, but it does not deform. It only crosses, like in a fluid, but it is not a fluid.

Student 8: Ok. Ok.

Teacher 3: Did you understand?

Student 8: Yes. It crosses, but the atom does not deform. It is not a fluid.

Teacher 3: Perfect!

In the dialogue, considering that Thomson's atom was like a cloud, the student asked the teacher if the atom was like a fluid. Then, the student asked if the atom would deform with the particles crossing it, and if such crossing would cause vortices inside the atom.

In this situation, we can notice that even if the metaphor was used to render an adequate understanding of the interaction between the alpha particles and Thomson's atom easier, the lack of immediate deconstruction of the metaphor generated several inadequate conclusions about the atom's structure.

In the situation transcribed, after he noticed the mistaken interpretation, the teacher devoted himself to explaining in detail which aspects of a cloud should be applied to understanding Thomson's atom. In other words, the teacher deconstructed the metaphor, which allowed the student to notice that the cloud was similar to Thomson's atom only regarding penetrability, while other aspects, such as a deformation or the existence of vortices, did not apply to the atom.

Based on this situation, we can conclude that the option to use metaphors may be an obstacle to learning if the compared elements are not made explicit, that is, if the metaphor is not deconstructed.

Situation 3 – Emphasis on Mass Concentration in the Nuclear Atom

This last situation took place in the 1st implementation of the course with students from São Paulo State. In this case, the approach chosen for the teacher to deal with atomic structure proved to be inadequate, and in fact served to reinforce students' mistaken conceptions.

In the lesson, after the activities that dealt with the replacement of Thomson's atom with a more-current model, the teacher chose to approach the idea of the nucleus of the atom according to mass concentration:

Teacher 4: Thus, the question is: there is a fact...What is the fact? That alpha particle came back with a large angle. It should not have come back, but it did. It is a fact, I cannot deny that. How can I explain that fact? How could it come back? So, I gave the example of the truck and the bike: if it finds a bike inside, does it strike the bike and go back?

Students: No.

Teacher 4: It will go over it. So what does it have to find there?

Student 2: Another truck.

[*Incomprehensible passage*]

Teacher 4: So, another truck? If the alpha particle is massive, if it has a large mass as compared to the other entities that we have seen there, what has it found inside there? What mass did it find inside there? What would be the mass of that? How should it be?

Student 3: The same as its mass.

Teacher 4: Also a large mass, right? Exactly. It should have a large mass. Correct? Yes?

Students: Yes.

Teacher 4: Because only if it found something with a large mass would it return. Another thing: However, what is the problem?

Student 5: What is that large mass?

Teacher 4: We have even thought about what that large mass is already. Now, something else that remains is that the majority went by. The majority went by. And a few came back, and those that came back encountered something with a large mass. What can I conclude from that? The majority went by, the majority went by, but a few came back, and they encountered something with a large mass. Only a few came back. What can I conclude? I already know that there is something with a large mass here. What else can I conclude if the majority went by and a few came back? I know that the mass is large, of that thing that is inside. What else do I know? The structure. Think about the structure. Is the size of that thing inside big?

Student 4: Yes.

Teacher 4: It may be something small. A small thing that is inside. Because most particles go by. However, when the alpha particle encounters that small thing, which is small but massive, it comes back. That led to Rutherford's idea that mass was almost entirely concentrated in the nucleus and that the nucleus was something small.

As can be seen, the teacher chose to explain the nucleus of the atom by emphasizing mass concentration using a truck-bike analogy which later proved inadequate.

Another teacher who was watching the explanation, noticing that charge concentration – the most relevant aspect of the nuclear atom – was not being approached, intervened:

Teacher 5: And there is another issue that arises, that not only… you have to think not only about the issue of mass, but also about that of charge.

Teacher 4: Charge. It does not have to do only with the effect of mass, but also with that of charge. With the positive charge being entirely concentrated there. And then the alpha particle is positively charged, it encounters something with a positive charge, which is also massive, it goes and [he makes gestures representing a trajectory of the particle getting closer and then being deviated by repulsion].

Student 8: Doesn't the charge of the electron have an effect?

Teacher 4: Hardly any. The deviation is due to the positive charges… hardly any is due to the negative charges. Why is the deviation due to the negative charges so limited?

Student 5: Because they do not repel each other.

Teacher 4: No, as far as the alpha particle is concerned, is its trajectory scarcely influenced due to the negative charges? We have seen that before… What is the mass of the electron as compared to the mass of the proton? In other words, what is the mass of the electron as compared to the mass of the atom? We have already discussed that, it is very small, isn't it? Rutherford already knew that the mass of the electron as compared to the mass of the alpha particle is very small. Almost 3,000 times smaller. No, 2,000 times smaller. Almost 2,000 times smaller than the mass of the alpha particle.

Teacher 5: And that is exactly what [Teacher 4] was talking about with the truck and the bike.

Teacher 4: So there are two things involved there, the sign of the charges and the mass. Therefore, although the electron is negatively charged, it will attract the alpha particle, but the alpha particle has an enormous mass. When it comes close to the electron it feels its power, its electric power, but it undergoes a small deviation. That is what I have said, it is about moving the truck with the bike. Of course, it will not deviate from its trajectory. Ok? These two things are acting there, both the sign of the charges and the mass.

Teacher 5's intervention seems to have been positive, since, right after it, Teacher 4, who was teaching the class, inserted the issue of charge concentration in his discourse. However, in order to answer the question posed by Student 8 (whether the charge of the electron did not act upon the alpha particles), the teacher returned to the prior explanation emphasizing mass.

After that discussion, the students gathered in groups in order to attempt the proposal of a new model of the atom, which, according to course planning, was expected to be similar to Rutherford's nuclear atom. Next, the models that each group proposed were presented to the entire class. All the groups presented models with one nucleus, but only one indicated the concentration of positive electric charge in the nucleus, whereas the others indicated exclusively the concentration of mass in the nucleus.

Figure 5 shows a drawing of an atom and its nucleus made by one of the students of the groups that proposed an atomic structure indicating only mass concentration ("massive nucleus"). In turn, Figure 6 shows the drawing made by one of the students in the group that proposed an atomic structure emphasizing charge concentration ("Nucleus charge +": nuclei with positive charge).

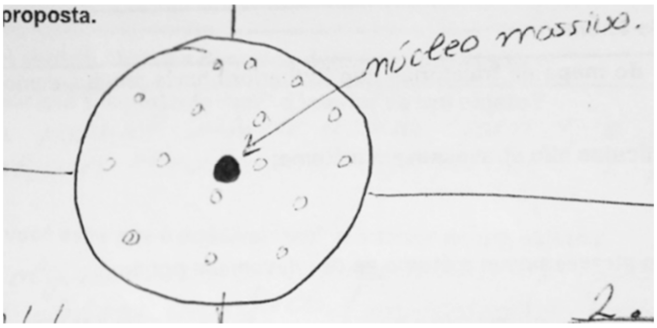

Figure 5. Student drawing with atomic structure indicating the concentration of mass in the nucleus

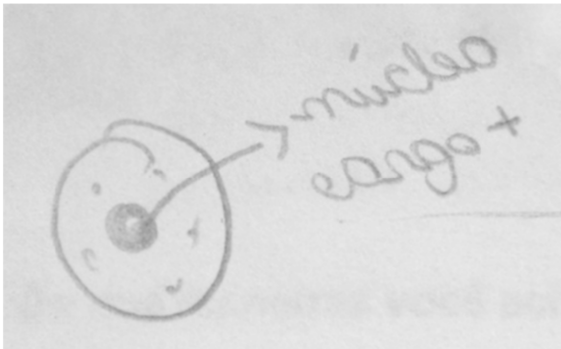

Figure 6. Student drawing with atomic structure indicating the concentration of positive electric charge in the nucleus

As can be seen, Teacher 4's emphasis on mass concentration was a didactic obstacle. Such an emphasis could even reinforce an epistemological obstacle that is common in the teaching and learning of the structure of matter: the idea of mechanical collision.

FINAL IDEAS

Considering that, in qualitative terms, there is no clear separation between concept and technique in the knowledge deriving from modern and contemporary physics, the course simultaneously favored discussion of the structure of matter and of particle accelerators. Besides, due to the counterintuitive nature of the knowledge approached, the course was conceived in such a way as to allow a gradual construction of the target conceptual model (particle accelerators), starting with a relatively simple conversation about why one should study the inside of matter. Later, teachers initiated a discussion of technique based on an analogical experiment, followed by an examination, from a historical point of view, of the replacement of Thomson's atom. Finally, particle accelerators were discussed.

Our historical approach, besides serving topics required in the curricula both of Cataluña and of São Paulo State (the study of atomic models), in effect subsidized later discussions about what particle accelerators do and how they work as equipment that allows the study of the structure of matter and subatomic phenomena, based on a technique of indirectly obtaining "hidden" information.

In the various implementations of the course, we identified several obstacles to learning about the subatomic world of physics. Some of those obstacles, those of an epistemological nature, consisted in the use of the perceptions of daily experience in order to try to understand the subatomic world. Other obstacles, of a didactic nature, involved didactic choices made by teachers that proved to be scarcely adequate.

As has been seen, both the texts and images chosen, as well as the use of metaphors that were not deconstructed, and the misleading emphasis given in one explanation of the atomic nucleus, were didactic obstacles that actually reinforced the mistaken perceptions of the students.

As was mentioned, the course was designed to allow a gradual understanding of key concepts involved in the study of the structure of matter, as well as the study of the technique that was used. Overcoming mistaken perceptions and comprehension of technique are of central importance to understanding particle accelerators.

In general, it can be stated that both in the elaboration of the material and in the choice of teaching approach, teachers themselves must pay attention to the difficulties of the topic of modern and contemporary physics. In the case of the particle accelerator theme, as has already been emphasized, the physical world explored is inaccessible to the human senses and, moreover, is a counterintuitive one, which disrupts our deeply-held notions about and perceptions of the accessible world. For example, in the subatomic world, interaction does not occur by contact, but, instead, involves distance interactions (electric power and nuclear powers), particles penetrate matter, and wave-particle duality must be taken into account. These last are among the many aspects of the subatomic physics that require the close attention of the teacher.

NOTES

1 Spain's post-obligatory high school, called *bachillerato*, offers two years of courses and normally serves students between 16 and 17 years of age. It is a pre-university program, directed by area of interest and devoted to preparing for future studies at the university level.

2 We use the term *previous conceptions* to refer to the set of notions built in daily experience and to the set of conceptual elements that students were already expected to know because they had been studied before in the classroom.

3 A text in Portuguese describing how the experiment was designed is available from http://www.sbfisica.org.br/fne/Vol11/Num2/a04.pdf (accessed November 17, 2014).

4 The *Rutherford Scattering* and *Up Close Rutherford Scattering* simulations were used, both of which were created by a Canadian Research Center: The King's Centre for Visualization in Science.

The simulations used, as well as others involving modern physics, may be accessed from http://www.kcvs.ca/site/projects/physics.html (accessed November 17, 2014).

5 The simulation *Scattering and Structure*, which was also created by The King's Centre for Visualization in Science, was used.

6 The original text in Catalan: "*Els àtoms dels elements consisteixen en un cert nombre de corpuscles carregats negativament, immersos en una esfera amb càrrega positiva i massa*".

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Márlon Pessanha
Departamento de Metodologia de Ensino
Universidade Federal de São Carlos
Brazil

Maurício Pietrocola
Department of Teaching Methodology and Comparative Education
School of Education of the University of São Paulo
São Paulo-SP, Brazil

FABIANA B. KNEUBIL AND MAURÍCIO PIETROCOLA

4. A TEACHING-LEARNING SEQUENCE ON THE CONCEPT OF MASS AND REQUIRED SKILLS FOR TEACHING RELATIVITY

INTRODUCTION

Researches on physics teaching have been going on for several decades and curricular innovation is an important and recurrent theme in such research worldwide. In Brazil, several researchers have considered the insertion of modern physics materials in high school courses, mostly as methodologies and strategies. Since the 1980s, studies have emphasized the need for curricular changes in order to incorporate modifications in worldviews that scientific theories, such as those regarding special and general relativities and quantum mechanics, have promoted (Terrazzan, 1994; Ostermann & Moreira, 2001; Moreira & Valadares, 1998; Gil et al., 1987; Ostermann & Cavalcanti, 1999). The need for these changes is shown in the fact that technological developments derived from 20th-century scientific knowledge have been incorporated into society and, thus, commensurate transformations in teaching are required.

Nowadays, many researchers take interventionist approaches, proposing teaching strategies involving modern topics, presenting discussions of the results of certain methodologies, developing didactic sequences regarding different contents, and analyzing the role of teacher training in curricular innovation (Brockington, 2005; Nicolau Jr., 2014; Lawall et al., 2010; Pietrocola et al., 2009; Siqueira, 2006). A research group at the University of São Paulo, called Research Nucleus in Curricular Innovation, delivers modern physics courses to Brazilian high school teachers, using their own didactic materials. Its educational research has focused not only on modern physics content, but also on how to promote the insertion of these innovative topics into the classroom.

The group deals both with didactical-methodological issues and with teacher training. To increase the effectiveness of innovation, the guiding principles of didactical reform must also be present in teachers' practices. Teachers are the most sensitive actors in the educational process and their training represents a great challenge. Implementing change is not an easy task.

As part of the crisis of science education, teachers are required to address the importance of the study of science without being specifically trained to deal with related difficulties (Fourez, 2003). According to Chevallard (1991), teachers work within a didactic transposition process and are subject both to external pressures and to the influences of the teaching system. Teachers are normally pushed into doing the work of the didactization process for school contents, in order to adapt

M. Pietrocola & I. Gurgel (Eds.), Crossing the Border of the Traditional Science Curriculum, 61–72.

them to new objectives imposed by higher instances. Teachers do have their own conceptions and experiences, and this may be the reason why they tend to react to innovations (Pinto, 2005). Issues like these give rise to problems, risks, and the possibility of failure (Davis, 2003).

This chapter[1] describes a case study concerning the performance of a teacher during a Teaching-Learning Sequence (TLS). This specific educational sequence addressed the concept of mass in three different contexts, namely classical mechanics, electromagnetism, and relativity, and emphasized epistemological and conceptual changes in mass from Newton to Einstein. The teacher was invited to both participate in the design of our TLS and to implement the developed course into the classroom.

During his classes, we could observe the difficulties he encountered, which generally arose in dealing with innovative subjects and epistemological content. This led us to suggest a set of relevant skills which could be required for implementing modern physics topics in the classroom.

MOTIVATION FOR THE CONCEPT OF MASS THEME

This chapter was motivated by the careless widespread use of the famous expression $E=mc^2$, which represents mass-energy equivalence. It is, definitively, the most popular formula in physics and can be found everywhere, both inside and outside of schools, in the media, even on T-shirts, etc. In educational institutions, both in high school and basic university courses, the formula $E=mc^2$ is usually not discussed in any depth.

Mass, normally associated with matter, is one of most fundamental concepts in basic education. Since the beginning of physics teaching, mass has been presented as a founding entity. In Newtonian mechanics, mass and matter are treated as identical and associated with the properties of inertia and attraction. After about two centuries of classical mechanics, energy was incorporated and related to mass in expressions of kinetic and potential energies. In the early 20th century, special and general relativities transformed the classical relationship between mass and energy. The best-known resulting change is embodied in the expression[2] $E=mc^2$.

One of the consequences of relativity is that inertia and attraction become properties of energy and are no longer framed as properties of matter. Another change is mathematical: mass does not depend on frame of reference and is a relativistic invariant. The ontological nature of mass is quite relevant to current physics, since it is a facet of the Higgs boson.

Despite their importance, these epistemological changes in the concepts of mass and energy seem to never quite reach most educational spheres, such as high school textbooks, undergraduate courses, and their various syllabi. There is a huge gap between the worldview introduced by relativity and typical physics education and, unfortunately, teachers have not had adequate access to this re-signification of mass and energy. More than a century after this shift, discussions on the implications of relativity are not yet part of most school knowledge – and this is especially true for the expression $E=mc^2$, which is often used only as a simple numerical conversion of mass into energy.

In our research, we developed a didactic sequence regarding the concept of mass, approaching the changes in the meaning of mass over three centuries, from Newton to Einstein. Part of our work consisted in proposing a didactic transposition of these topics,[3] ranging from scholarly knowledge up to knowledge taught, as defined by Chevallard (1991) in his Didactic Transposition Theory.

DESIGN-BASED RESEARCH AND TEACHING-LEARNING SEQUENCES

Design-Based Research (DBR) is a methodology that emerged in the 1990s, based on interventionist methods, and with the goal of joining the theoretical aspects of educational research and practice. This methodology was introduced in the educational context by Brown (1992) and Collins (1992) and, afterwards, employed by other educators as well (Richey et al., 2004; DBR-Collective, 2003). DBR emerged as a form of research that implements educational innovation in real classroom environments and that deals with the entire teaching process, starting from the idea of innovation and following through to its actual implementation. The results that arise from a given implementation process must be incorporated into the methodology itself, aiming at its improvement.

It is important to emphasize the interventionist features of DBR, since these are what promote links between the theoretical and the practical dimensions. Van den Akker (1999) emphasizes that the relation between theory and practice is very complex and that, sometimes, the direct application of theory is not enough to solve practical issues. Therefore, he argues that

> a more ‘constructivist’ development approach is preferable: researchers and practitioners cooperatively construct workable interventions and articulate principles that underpin the effects of those interventions. Another reason for cooperation is that without the involvement of practitioners it is impossible to gain clear insight into potential implementation problems and to generate measures to reduce those problems. (Van den Akker, 1999, p. 9)

In the teaching context, DBR methodology has been used to design, implement and evaluate Teaching-Learning Sequences (TLSs) on specific science subjects. Many educational researchers argue that general education and learning theories do not account for solving problems related to practice. According to them, theories unrelated to specific science subjects do not ensure didactical quality in teaching (Lijnse & Klaassen, 2004). These authors contend that ‘flight away from content’ causes a gap in the didactical dimension, and thus a lack in certain elements necessary for the promotion of didactical progress. They also emphasize that

> the missing level is that of describing and understanding what is, or should be, going on in science classrooms in terms of the content-specific interactions of teaching-learning processes, and of trying to interpret them in terms of didactical theory. (Lijnse & Klaassen, 2004, p. 538)

The notion of TLS has been widely used in investigative research regarding the cognitive learning of both students and teachers. However, in the present research, the name TLS refers to an investigation guided by specific topics (Méheut & Psillos, 2004). Teaching-Learning Sequences are both an activity of interventionist research and a product, and include designed learning activities empirically adapted to the reasoning of students and to the classroom. The development of TLSs takes into account specific issues, such as student conceptions, the particularities of specific contents, epistemological assumptions, learning perspectives, pedagogical approaches, and the features of didactic contexts.

At the end of the implementation process, it is expected that the data and results produced should contribute to an increase in the amount of knowledge in the didactical dimension associated with a specific science content. According to Lijnse (2010), there is a level of didactics that is often skipped over or left to the teacher (level 2, in Figure 1) and design-based research aims at filling this missing level.

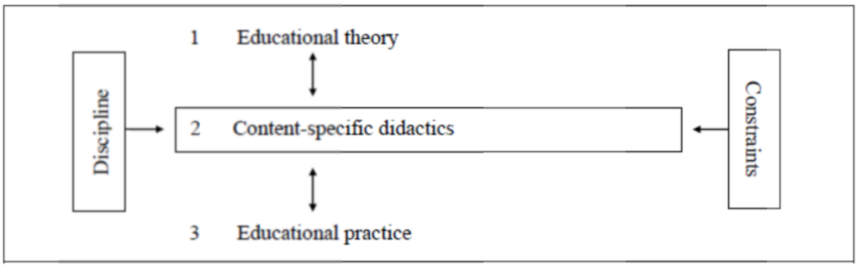

Figure 1. Level of didactics (from Lijnse, 2010, p. 145)

In short, DBR has been shown to be promising, because results from its implementation may produce knowledge that contributes to a given didactical theory. Traditional education theories tend not to support teacher's actions in the classroom. Hence, there is a need to develop knowledge to be taught that can be applied in real contexts. Scientific school knowledge must be associated with this methodological-didactical knowledge. Tiberghien (2000) encourages educators and researchers to develop didactical sequences about more challenging topics, since designing them for all science subjects is not feasible. As the features of scientific knowledge are general, the results generated by such implementation can be transferred to other contexts and applied by other teachers. These results can provide new didactical knowledge and improve practice, even in the case of experienced teachers. They can enlarge teachers' awareness about situations and difficulties regarding certain topics. It would take a long time for similar advances to be incorporated into the practice of teachers working on their own.

In general, during the design of a TLS about specific science contents, the researcher and the design team often specify research questions, which guide the investigation and evaluation. The results of our TLS on mass/energy research are related to this kind of question.

OUR TEACHING-LEARNING SEQUENCE ON THE CONCEPT OF MASS

Our TLS is called ‘$E=mc^2$ and the Weight of Energy’. It was developed in the University of São Paulo between 2012 and 2014, and was designed for experienced high school teachers. As far as methodology was concerned, we adopted the usual TLS framework, as described in the previous section, and supplemented it with ideas from didactic transposition theory, including the three spheres of knowledge (scholarly knowledge, knowledge to be taught, and knowledge taught), didactic intention, and epistemological vigilance (Chevallard, 1991). These concepts are important for our work, since our research concerned the teacher’s performance and, according to Chevallard, the teacher must convey his or her didactic intention to the classroom.

Our investigation regarded the transferability of didactic sequences related to the concept of mass. We concentrated on the following two issues:

1. Is the design process alone enough to prepare a teacher to deal with innovative contents?
2. What are the skills a teacher must have for teaching modern physics topics?

With these two questions, we wanted to understand the importance of the teacher’s expertise in a curricular innovation setting and to take into account his training and previous knowledge. We analyzed the same teacher in both classical and modern physics teaching contexts. In addition, we hypothesized that the skills required to teach in each setting would be different.

We began by reviewing the concept of mass in three different frameworks, namely classical mechanics, electromagnetism, and relativity. This highlighted the fact that the properties of inertia and attraction, which were attributes of matter in Newtonian mechanics, shift to energy in relativity theory. Motivated by the perception that discussions of the formula $E=mc^2$ are practically absent in textbooks used in both high school and introductory university courses, our study was recorded in a written document of more than 150 pages. Later, this text was used to develop the DBR didactic sequence.

The design team involved three collaborators: the co-authors of this chapter, a professional physicist, and the implementing teacher, under the supervision of one of us (F.B.K.). The design stage lasted about four months, with 12 meetings. After this process, the design team defined the Design Principles and Objectives of the Course, described below.

Design Principles

In DBR/TLS methodology, design principles have a high level of importance. In our case, they are related to the structure of scientific knowledge and have, therefore, an epistemological nature. We started from two principles: (a) scientific concepts evolve and their meanings change over time – as when relativity re-signified the concept of mass; (b) maps and networks are indispensable in understanding concepts – scientific knowledge is organized in conceptual structures and the meaning of each concept is defined by other nearby concepts (Kneubil & Robilotta, 2015).

Objectives of the Course

The objectives of this course on the concept of mass are quite broad and more concrete than the principles stated above. They were present throughout the whole process, guiding the construction of the didactic sequence.

- Main Objective: to highlight the changes of the concept of mass from Newtonian Mechanics to Relativity.
- Secondary Objectives: the secondary objectives regard the methodological dimension and consist of the following: (a) to show that the formula $E=mc^2$ is not superficial and conveys very rich ontological information – conceptual objective; (b) to show that conceptual structures allow a better understanding of the concept of mass – epistemological objective; (c) to show that the fragments of $E=mc^2$ available in textbooks, curricula, and syllabi do not allow a clear understanding of the subject – curricular objective.

The Course Plan

The didactic sequence on the concept of mass was designed with eight lessons, divided into three on classical mechanics, two on electromagnetism, and three on relativity. Each lesson was planned to last two hours and a short description of each is presented below.

Lesson 0 – The Classical Universe
The General Contents of the Universe – Space and Time – Mass and Gravitational Field – Newton's Law of Gravity – Newton's Laws of Dynamics – The Universe as a stage, with material actors

Lesson 1 – Energy and Work in Classical Physics
Energy and Momentum related to Space and Time – The Role of Force – Gravitational Potential Energy – Mass and Inertia

Lesson 2 – Bound Systems and the Hydrogen Atom
Confined Systems – The Potential Well – Coulombic Potential – The Energies of the Atom – Binding Energy – Epistemological Discussion – Exothermic Reactions

Lesson 3 – Energy and Momentum in Electromagnetism
Charges and Fields – The Energy of Fields – Stored Energy in Capacitors – Point-like Charge Energy – Electromagnetic Waves – Momentum of Waves – The Re-Signification of Momentum

Lesson 4 – Radiation and Action-Reaction
Electric Field Lines – Deceleration of Electric Charge – The Origin of Radiation – The Breaking of Newton's Third Law – Momentum Conservation – Re-Signification: Wave carries Momentum

Lesson 5 – Relativity: Relative and Absolute Entities
Relativity in Spatial Rotations – Special Relativity Theory – Lorentz Transformations – Scalar Products – Relativistic Interval – Proper Time

Lesson 6 – Relativity: Mass and Energy
The Classical Coil-Magnet Problem – Four-Momentum – Energy as the Fourth Component of the Four-Vector – Energy and Inertia – Invariant Mass – The Re-Signification of Mass

Lesson 7 – $E=mc^2$ in Action
Exothermic Reactions – The Energy of the Photon – Relativity and Lavoisier –The Weight of Hydrogen – The Weight of Deuteron – The Weight of the Proton – Re-Signification: Energy has Weight!

General Features of the Course

This course can be considered as a kind of didactical narrative, one which conveys a message. All the topics mentioned above were carefully ordered to preserve global meaning. The course was designed taking into account the main objective, which is the re-signification of mass, at all stages of the process. Some elements of the course were chosen to highlight the construction of important underlying concepts, such as mass, inertia, gravity, momentum, and energy, in classical mechanics, electromagnetism, and relativity. In order to accomplish our objectives, these topics, which make up a didactic structure, were classified as means-like or ends-like.[4] This idea is represented in Figure 2.
The means-like elements are contents outside the main axis of the course. They may be related to other concepts and are intended to make up possible content gaps, as well as to strengthen basic contents. Therefore, the role of means-like elements is mostly local.

The other topics, namely ends-like elements, have to do with approaches considered key to understanding the global picture. They make up the main axis of the didactic narrative and deal with both dimensions of scientific knowledge, namely extension and depth (Kneubil & Robilotta, 2014). The goal of the ends-like topics is to insert physical concepts into broader contexts. Some lessons aim at

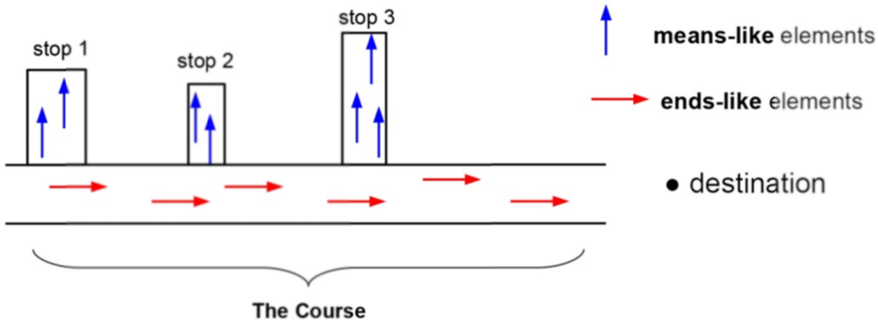

Figure 2. Elements of the course

rendering ontological features of concepts explicit and allowing a blend with epistemology. When this happens, a greater integration occurs in a deeper layer of our cognition. The framework of ends-like elements is global and it acts towards structuring knowledge and giving new meanings to concepts.

In every lesson means-like and ends-like topics were presented; what distinguishes the two is their relation to didactic intention, as well as the teacher's approach to each type.

DIDACTIC RESULTS

According to Lijnse (2000), one of the goals of developing and implementing didactic sequences is to extract results and knowledge for didactic theory in general. The implementation of our Teaching-Learning Sequence allowed us to realize some aspects related to the practice of teaching modern contents, especially those concerning relativity.

Our research essentially involved two axes, namely the physical course content and the achievement of the implementing teacher. The first one led to the elaboration of the course proposal on the concept of mass, which corresponds to a new didactic transposition, i.e., new school knowledge. Regarding the second axis, by analysing the teacher's classes, we could observe the difficulties encountered in transposing this knowledge into the classroom. Therefore, the creation of didactical knowledge in this investigation had to deal with both the contents developed and the teacher's didactic skills.

Throughout the process of design and implementation, we recognized five skills directly associated with the specific content of this course. They are described next.

Recognition of the Functionality of Prerequisites

Knowing how to choose elements that are adequate for teaching innovative topics is essential and effective in optimizing, enhancing, motivating, and streamlining the classroom teaching process. In the course we developed, for example, we inserted a calculation of a diagonal cube module in three-dimensional space in one lesson. This was done because we knew that two classes later we would discuss four dimensions in relativity. Choosing prerequisites in a fair and necessary way and recognizing their functionality are not simple tasks. This competence is very important in ordering the contents necessary for the structure of didactic sequences, especially when implementing innovative research, as with this TLS. Our education does not typically include or develop this kind of skill, as our school experiences as students are usually entirely based on traditional contents lists arranged into curricular frames. Therefore, this competence is not a natural result of our training and it must be taught or guided in order to be implemented in the teaching of physics, especially in short courses that involve thematic sequences.

Knowing How to Re-Signify Physical Concepts

In modern physics, concepts change their meanings and, therefore, knowing how to re-signify them is necessary in order to move from one theory to another. The re-signification of concepts in physics is associated with the restructuring of theories, since the meaning of one concept depends on the context in which it belongs. We were able to verify the importance of knowing how to re-signify concepts during the implementation of this TLS. The exercise of this skill requires a broader view of physics and knowledge of other contexts beyond the particular one that the teacher is addressing in a given activity.

Knowing How to Interpret Equations

Most of the time, physics ideas are represented through mathematical expressions. Extracting these ideas from equations and interpreting them both require complex skills, which the teacher must have. In order to gain these skills, extensive experience in teaching such content is necessary. In the case of relativity, even apparently simple equations are impregnated with the notion of changing frameworks and, for this reason, they are much more difficult to interpret than those of classical mechanics.

Familiarity with Abstract Concepts

Abstraction is a fundamental feature of scientific knowledge and thus physics teachers must be able to work with abstract concepts. In classical physics, such concepts as time, force, field, velocity, and energy are already very abstract. However, in relativity, they are incorporated into higher structures, which render them even more abstract. For example, the concept of space is thought about as a four-dimensional entity, incorporating four-vectors with four components. To understand the meaning of the four-vector modulus in relativity requires complex abstraction, since it mixes space with time. Our Teaching-Learning Sequence incorporated many of these abstract concepts such as proper time, relativistic interval, and relativistic mass. It allowed us to discover that the effective teaching of such concepts is related more to the capacity to abstract than is the case for classical physics concepts.

Knowing How to Transform Questions

This skill is related to the perception of the specific problems and issues dealt with in classical versus modern physics. It is very important in modern physics contents, and is in fact a required skill when students ask questions. An inexperienced teacher has a greater chance of making mistakes if he or she is taken aback by a question as it is asked by the student. This may happen because the problems that each theory solves are different. The way we think about concepts and how we deal with physical situations are unique to relativity. This conception of relativity leads to a specialized way of discussing questions that is found only in the study of relativity. If a student raises a problem based on classical thought, the teacher must have the insight to recognize that basis, and to reformulate the student's question by bringing it back to the context of relativity. This action is entirely positive, because it teaches students that to think in the field of relativity also involves placing problems and questions within the framework of the theory. This skill requires experience in – and ongoing practice of – teaching modern physics themes.

These five skills are directly related to the teaching of modern physics. The inadvertent practice of teaching classical physics must not develop in the teacher's enactment of these competences. Each skill is connected with the capacity to act in consonance with modern physics content and is essentially required by the nature of the content itself. The ability that the teacher has to address each aspect of content influences his or her lesson in a definitive manner, giving to it a more or less didactic quality, depending on his or her skill levels in these five areas.

NOTES

[1] The results and discussions present here are part of a doctoral dissertation (Kneubil, 2014), which describes the epistemological route of mass-energy equivalence and analyzes the teacher's performance in the implementation of a Teaching-Learning Sequence on the concept of mass.

[2] Although the formula $E=mc^2$ suggests the equality between mass and energy, in the theory of relativity, mass is a scalar entity and energy is the fourth component of a four-vector. It would therefore be more appropriate to write it as $E= \gamma mc^2$ (Okun, 1989; Hecht, 2011, 2006; Kneubil, 2014).

[3] The complete instruction material can be found in Kneubil (2014).

[4] I use the words 'means' and 'ends' here as in the saying: 'The ends do not justify the means'.

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Fabiana B. Kneubil
Department of Physics
Federal University of Santa Catarina (UFSC)
Florianópolis-SC, Brazil

Maurício Pietrocola
Department of Teaching Methodology and Comparative Education
School of Education of the University of São Paulo
São Paulo-SP, Brazil

LUÍS PAULO DE CARVALHO PIASSI,
RUI MANOEL DE BASTOS VIEIRA, AND
EMERSON IZIDORO DOS SANTOS

5. SCIENCE STAND

Crossing Borders between Sciences, Arts, and Humanities in a Decentralized Science Dissemination Program

BACKGROUND AND PRINCIPLES

Our current research interests derive from our previous experiences as graduate students in the second half of the 1990s, in two physics education projects that existed at that time at the Institute of Physics of the University of São Paulo. The "Experimentoteca-Ludoteca" (perhaps most fittingly paraphrased as "Playful Library") Project, coordinated by Professor Norberto Ferreira (1993), developed low-cost, playful experimental resources for science teaching, by using simple and familiar materials to reproduce classical didactic experiments and toys for learning about mechanics, electricity, optics, and so on.

The "GREF – Grupo de Reelaboração do Ensino de Física" (or "Physics Teaching Re-Elaboration Group"), managed by Luis Carlos de Menezes and Yassuko Hosoume (1993), proposed materials and methods for an approach to teaching physics that was based on everyday life. Discussion of such subjects as mechanics, thermodynamics, and electromagnetism was based on things students use, see, or are interested in in their daily lives, such as electronic gadgets, vehicles, home appliances, etc.

In addition to providing the experience necessary for the production of didactic material, such activities were the basis of our participation in ongoing training programs for teachers; we were also able to work directly with several such programs. Concerns about elementary schools have become systematic since we joined the "ABC na Educação Científica – Mão na Massa" (ABCs of Science Education – Hands-on Science) program in 2005. This is an inquiry-based science education (IBSE) program, intended mainly for elementary schools, and it derives from the French program "La Main à La Pâte",[1] and from the contacts that Professor Norberto Ferreira had with the Nobel-Prize physicist Georges Charpak. The implementation of this program in Brazil occurred in three initial outposts in institutions of non-formal science education, namely "Fundação Oswaldo Cruz" (Oswaldo Cruz Foundation, known as Fiocruz), in Rio de Janeiro, "Centro de Divulgação Científica e Cultural" (Center for Scientific and Cultural Dissemination, or CDCC), in São Carlos, and "Estação Ciência" (Science Station), in São Paulo, the last two being affiliated with the University of São Paulo. The

M. Pietrocola & I. Gurgel (Eds.), Crossing the Border of the Traditional Science Curriculum, 73–93.

Brazilian Academy of Sciences program supports the program, which is still active in settings all over Brazil. We were part of the “Estação Ciência” (Science Station) ABC program throughout almost our entire doctoral courses. Since 2008, we have been gradually admitted as professors in the University of São Paulo (USP) and in the Federal University of São Paulo (UNIFESP), where we are undertaking our current research.

One important aspect with which we have been concerned since the outset of our studies, is the role of knowledge sources other than textbooks and the traditional didactic resources usually employed in science teaching. Experiments can be more than a lively way to explain concepts, they can be a source of real pleasure as well, just like the toys, games, and other cultural products liked and enjoyed so much by children. One of the bases for such considerations was the work of the French pedagogue Georges Snyders. In the 1980s, he wrote a book entitled “Le Joie à l´École” (Snyders, 1986), in which he explored the contradictions that exist between the cultural forms that the school system proposes and those with which children are so intensely engaged outside of the classroom, such as music, sports, concerts, fashion, and flirting, among others. He wondered if it would be possible to engage students in an “elaborated culture”, which schools could provide, as much as they engage with their “primary culture”, which derives from their spontaneous experiences. In other words, how could schools provide young people with a similar and even deeper joy in knowledge?

There are many possibilities for the development and testing of these ideas. Since around 2004, based on personal classroom experience with the use of science fiction to teach science topics, we have developed several classroom activities utilizing science fiction films, novels, and short stories. We have started to use these materials not only for discussion of the products of science – concepts, laws and phenomena – but also the mechanisms of scientific knowledge production and the relationship between science activity and social context.

For a Ph.D. thesis (Piassi, 2007) based on these practical experiences, we investigated and studied science fiction itself and we conducted research about classroom experiences involving science fiction. These studies provided a basis for the development of instruments for theoretical analysis in dealing with science fiction from the point of view of the science teacher. Classroom approaches to science fiction are often based the somewhat naïve approach of identifying science concepts and discussing the distortions of “real” science presented in stories. By instead considering science fiction as a fictional construct built over a social discourse about science, we were able to deal with such “errors” and “distortions” from another point of view. Instead of distortions, we can consider certain ideological positions about science that we can identify in works of science fiction. Most of the time, such positions can be described in terms of polarities, in which each of the poles represents beliefs or disbeliefs related to the roles that science plays in our lives.

Thus, we obtained a theoretical framework to address not only the application of science fiction itself, but also a broader field of cultural products to be (potentially) inserted in the science education context, from playful experiments to toys, films, books, songs, and so on. We were looking for ways to incorporate as many of these tools as possible, considering the pleasure that such things provide to young people in their spare time. However, as Snyders (1986) points out, even though such spontaneous joys are real, they are also at the same time ephemeral and superficial. They pose the sorts of questions and interests that a more systematic and critical approach to reasoning could address in a more satisfactory way.

Since 2008, when one of us (Piassi) was admitted as a professor in the School of Arts, Sciences, and Humanities of the University of São Paulo (EACH-USP), it has become possible to investigate these ideas in more comprehensive projects. The EACH-USP is a non-departmental unit, a 10-year-old project of the University of São Paulo designed not only to create an advanced campus in a poor region of the metropolis that lacks public resources, but utilizing a training proposal adequate for facing the new challenges that certainly arise in such a context. It has ten very distinct undergraduate courses.[2] However, these courses of study do share several disciplines, including the natural sciences, arts & literature, conflict resolution, society & the environment, multiculturalism & rights, among others, in an attempt to facilitate general training as well as interaction between the different areas. This environment was favorable to the innovative and interdisciplinary proposals we hoped to institute.

Two initiatives emerged. The first one involved an ongoing training program for in-service public school teachers, using the IBSE approach and the innovative elements we were developing, from playful low-cost experiments to movies, games and other resources. We started with a 30-hour course called "Physics in the K-8 School: Interdisciplinary Activities in a Sociocultural Perspective", as a proposal for the ongoing education of science teachers based on Vygotsky's socio-historical theory (Vygotsky, 1978, 2012). This study enabled us to establish a method for the analysis of certain criteria in order to evaluate the choices between different approaches to teaching. Our studies point to the need to examine classroom activity according to multiple aspects that involve not only the conceptual realm and the individual actions of the teacher and the student, but also – and mainly – those activities related to social interactions in the classroom environment (Santos, 2010). On this basis, we planned a second course, a 360-hour course called "Specialization in Astronomy Teaching", in which we proposed to evaluate the model of teachers training teachers in a continuous manner designed to engage participants in the development and the undertaking of didactic activities through social interactions, again driven by Vygotsky's socio-historical theory. In order to monitor the teachers' didactic production, we developed two instruments: "improvement indicators" and "interaction profiles". The former enabled us to analyze and control the development process activities through formative assessment. Its aim was both to identify and to offer opportunities for correction and improvement by means of descriptive opinion. The latter, in turn, enabled us to analyze interactions among teachers within their working groups. We observed that the creation and development processes of these activities were directly related to the different ways in which these interactions occurred within the groups (Vieira, 2013). The second initiative was the “Science Stand”, or “Banca da Ciência” in Portuguese, which we will now describe in a detailed manner.

THE SCIENCE STAND

The diffusion of science happens to be a particularly interesting subject for us, particularly after our previous experiences at the “Science Station”. We are interested, above all, in ways to decentralize science centers. The main reason for this is that there are so few museums and science centers in Brazil. It is hard for most children to visit such facilities, even in large metropolitan areas, such as São Paulo. There, however, are several “mobile science” initiatives intended to bring the experience of museums and science centers to a wider audience. Among them is “Mobile Science” itself, a program of the Oswaldo Cruz Foundation, which uses a truck as science center.[3] Other interesting projects include “Art and Science in the Park” (Muramatsu & Robilotta, 2011), which offers science exhibitions in open public spaces, and “Truck with Science”, which uses a cargo vehicle to carry hands-on science exhibitions to public schools (Souza & Siqueira, 2011).

Our “Science Stand” fits in this category of projects. It derived from another project called “Ecoteca”, from the non-governmental organization Educare[4], which consists of mobile libraries for children built on structures similar to those used to sell magazines and newspapers. The project coordinator, Jonar Brasileiro, contacted one of our friends, the high school physics teacher, Ricardo Magalhães, who had the idea of adapting the Ecoteca model to mobile science centers. In 2009, Educare donated a stand to EACH-USP, in order to support research into developing this idea. Next, we asked various agencies for financial support, which made it possible to develop (in 2010-2011) both materials and exhibitions, as shown in Figure 1.

Figure 1. The first “Science Stand”, in an exhibition to public kindergarten teachers, on the Guarulhos campus of the Federal University of São Paulo – UNIFESP (2014)

At that time, our focus was on the development of materials that we could display in our “Science Stand”. These materials would be considered as basic components of an exhibition which should follow certain operating principles, or guidelines. One aspect we would like to emphasize is the expectation relationship. What kind of experience are visitors expecting when they come to an exhibition? According to Michelle Henning (2006), neither museums nor exhibitions are regularly seen as media, nor are they studied from cultural perspectives. Hence, it is rare to think about the implicit messages that certain choices express in the production of materials.

As a simple example, consider Henning’s reflection regarding the glass case often used in museums to display artifacts: “the glass case fetishizes objects by conferring an instant aura of preciousness. It places them in a space and time distinct from that which visitors occupy – protecting them from deterioration, pollutants, and changes in temperature” (Henning, 2006, p. 8). Henning gives this glass case example during her discussion of the well-known Marxist concept of commodity fetishism. Commodity fetishism is a phenomenon where people attribute essential value to the thing itself, instead of to the human labor necessary to its creation. In other words, the focus is on things, rather than on people:

> Commodity fetishism suggests an anthropomorphic relationship with material things, which we treat as valuable and meaningful in themselves, and capable of endowing us with certain desirable qualities. These relationships do not cease at the museum’s door. Museums are not immune to the changed relationships between people and things brought about in capitalism. (Henning, 2006, p. 8)

We do not want the visitor to see the “Science Stand” as a place of consumption, despite the “point of sale” metaphor implicit in its constitution. When we think of a stand or a stall, the acts of selling and buying come automatically to our minds. We go to a newsstand, or a stand at a fair, or a juice stall in order to buy something or, at least, to get informed about things (or services) which may be acquired or consumed. Instead, what we offer is a knowledge experience, with humorous elements as well as entertainment or leisure features that elicit a non-passive attitude from visitors. Visitors to the “Science Stand” are moved to decode situations, wonder about phenomena, and ask for answers to their questions.

This format breaks with expectations in that, at first glance, the visitor sees the “Science Stand” as a place where something is being sold, but instead what he or she gets is a learning situation, one which requires direct engagement, handling things, social interactions, and so on. Thus, it is not a consumption relationship after all. The very constitution of the things they will find at this stand is the antithesis of the mass-market industrialized products one can find in stores. In fact, what they will encounter is simple, handcrafted things that suggest the possibility of replication at home. This is the implicit message we want to convey. In our “Science Stand”, you are not going to buy something tricky to show your friends, as you might in a magic stall. You are not even going to briefly and passively watch a performance done by someone else. If you want to reproduce the “Science

Stand" experience yourself, you will be able to do so because the necessary ingredients are simple, manageable, and accessible.

In order to achieve these points, we defined a set of guidelines for the project's main features. Table 1 has to do with the general aspects of the exhibition, as a whole. Other tables refer to the production of exhibition artifacts, the constitution of the structure of the stands, and to the mobile features. Therefore, for the general (and somewhat ambitious) principles of the exhibitions, we propose the statements listed in Table 1.

Table 1. Guidelines for conceiving exhibitions

I	Engagement	Activities should not be established in a consumption relationship, with the audience in the role of mere receivers. They should encourage visitors' direct involvement by offering them situations that involve compelling challenges and problems.
II	Captivation	Exhibitions must be visible and able to attract, inspire curiosity, and provide experiences of wonder for the public. Their elements should clearly dialogue with both the cultural interests and the daily experience of visitors.
III	Repercussion	Activities must provide extended cultural repercussions that extend in time, even after they end, thus encouraging new relationships with scientific knowledge.
IV	Empowerment	The visitor should experience cultural enhancement from exhibit activities, which must not only provide immediate enjoyment or curiosity, but should promote reflection, knowledge, and suggestions for new ways to act in the world.

During that period, while our extended astronomy course for teachers was taking place, several of the artifacts proposed involved space topics, such as moon phases, seasons, and solar system models, among others. Other materials were inherited straight from the "Experimentoteca-Ludoteca" project, mainly equilibrium toys and simple electrostatic experiments. Others were inspired by other sources and involved such themes as fluid mechanics, optics, and waves, emphasizing physics topics. We also acquired some ready-made materials, some of which included professional science exhibition equipment. However, our priority was the sort of handcrafted games and toys commonly sold in artisan fairs all over Brazil, which our audience considers both simpler and more familiar.

As we conceived, selected, and adapted the material, we conceived of some points to follow, derived from principles already established in previous projects. These defined a set of guidelines for material production, according to Table 2. We think about these guidelines as a proposition according to which science is something close to people and we contend that anyone can produce knowledge. Science is not an activity restricted to geniuses and it does not always require expensive and sophisticated equipment.

Figure 2. Two artifacts of "Science Stand". Left: The "Upside Down Ladybug", a handcrafted toy that turns over by itself, as a center of gravity effect. Right: A Humphrey-Davy Lamp assembled with simple hardware

Table 2. Guidelines for exhibition artifacts in a "Science Stand"

I	Playfulness	The artifact must arouse curiosity and offer a pleasant experience to the visitor.
II	Simplicity	The artifact must be simple, and the public must perceive it in that way.
III	Familiarity	It must be easy to recognize both its materials and spare parts.
IV	Affordability	Both spare parts and materials must be low-cost and easy to find.
V	Reproducibility	Almost anyone should be able to replicate the artifact.

Since 2012, we have been receiving additional funding from the University of São Paulo (USP) and from federal agencies. Almost around the same time, one of us (Santos) became a science professor in undergraduate pedagogy at the Federal University of São Paulo (UNIFESP) in Guarulhos. These two events helped us to improve both our action model and the overall design model of the "Science Stand". We set standards in visual communication, materials, dimensions, exhibition devices, formats, monitors´ uniforms, and so on. One of the main developments was to plan strategies and materials making it possible to take small exhibitions to locations where it was impossible to carry the stand itself.

However, when we tried to move the stand from one point to another, we realized that its specific structure required a lot of specialized (and expensive) work to be adequate to itinerancy. In 2013, Educare supplied us with a second structure, which it designed, which was more adapted for transportation. It has wheels, a more robust steel frame, dimensions similar to an automobile, and handles designed to attach it to a truck body. Therefore, we could haul it with regular vehicle winches, a much cheaper service, available everywhere (Figure 3). In addition, this new mobile stand is designed to remain outdoors, and even incorporates a system to capture rainwater.

Figure 3. The new stand, designed for transportation by regular car winches, in the Youngsters Exhibition of the Brazilian Society of Science Progress meeting, at São Carlos Federal University (2015)

We used both stands in several events, and, by analyzing the results and circumstances of each, it was possible to assign some guidelines for the design of the device itself, as shown in Table 3. In general, our conclusion is that the stands must work as provisional but effective mini-science centers, with resources that allow their operation and, later, their being moved, as straightforwardly as possible. Therefore, versatility is crucial, because the specific conditions of locations are highly variable. In addition, insofar as it is possible, stands should not depend on local water and electricity supplies. For the former, Educare designed a water catchment system that is working fine in our current facilities. This NGO is also planning to adapt a solar energy system in order to store electricity in batteries inside the stand, but this is a future project.

Even with this better-designed stand, it was not that simple to present exhibitions in every desired or requested location. In some situations, it emerged as more effective or suitable to have equipment that was even more portable. We consequently adopted two strategies. The first maintained the idea of a kind of "point of sale" for science, but on a smaller scale, something like a fruit stall offering science instead of fruits. The first attempt of this approach can be seen in

Figure 4. The key requirement for this device was that it fit in a regular passenger vehicle, preferably in the trunk of a car.

Table 3. Guidelines for designing mobile stands

I	Mobility	The design of the stand must ensure low-cost, quick, and easy transportation, and it must not require any specialized or professional equipment. Educare’s solution was to install wheels on a regular, automobile-sized chassis, so that the stand could be hauled in the same way as cars, using regular winches. We are now investigating the best kinds of wheels for the irregular terrains (such as grass) often found in locations where we hope to utilize the stand.
II	Autonomy	One of the stands has a system designed to capture and store rainwater, which has worked fine for activities requiring water. As far as electricity is concerned, we are planning to install battery storage systems with capture by solar panels. Although we can sometimes rely on electric power points, we have noted that it is essential to have the capacity to rely on this possibility, not only for lighting, but also for the implementation of activities and experiments.
III	Security	The structure must be able to withstand bad weather, ensure security, and present resistance to invasive actions. The stand currently employed has been used and maintained in public spaces and, so far, there have been no problems in these regards. Some minor theft-preventative adjustments are being made regarding fixed installations that remain outside the structure. We are also formulating a locking system to prevent the whole structure from being removed from its site without authorization.
IV	Versatility	The framework should allow various types of activities to be presented with only minor adjustments. It should enable several different activities – such as interactive exhibitions, puppet theater performances, workshops, and audiovisual displays, among others – to occur simultaneously or in quick succession. All of the stand´s spaces (inside, sides, roof) have mechanisms for modular installation devices. Based on pilot experiences, we identified some equipment that will allow for this versatility, using widely-available materials such as the panels and fixtures often used to display products in stores.

We observed that our first model was both too heavy and too clumsy for our purposes, so we are building a smaller, lighter one. In any case, our intention is for such a device to be able to transform any space where it is located into a space of scientific exhibition.

The second “Science Stand”-associated strategy we adopted for science exhibitions was to create a visual identity that resembled a “point of sale for science”, just as the stands do. With that in mind, we chose standards for exhibition materials that were in tune with the reproducibility and simplicity of the ideas themselves. We projected displays in the form of 3-D posters, by using boards composed of perforated eucalyptus wood shavings. This is a cheap, versatile, eco-friendly material, which can accommodate both exhibition artifacts and small explanatory posters, as can be seen in Figures 1, 4, and 5.

Figure 4. The "Mini Science Stand" – The first model of an exhibition device that could be hauled by car

Figure 5. Exhibition for parents at a school in Guarulhos (2014)

After exhibiting to different audiences in several spaces and situations, we were able to develop some guidelines for displaying resources in order to ensure that project goals are fulfilled. These guidelines are described in Table 4.

Table 4. Guidelines for designing exhibition devices

I	Standardization	We established exhibition systems with their own identity and characteristics, which can be easily reproduced and which give prominence to the activity performed. With that in mind, we used widely available materials.
II	Mobility	Presentations in schools, events, and other situations require light materials and devices that can be easily transported, both by air and ground, without the use of specialized packaging or labor.
III	Versatility	The devices should be adaptable to different spaces and situations, be easily assembled in classrooms, halls, stands, lobbies, etc., and allow for various types of interactions, based on direct accessibility for and engagement with the visiting public.
IV	Modularity	Materials must be adaptable to several formats and sizes, and suitable for being combined in various ways for various kinds of exhibitions, including classroom use by teachers.

The focus of the project is not to reach the widest possible audience, nor is it to disseminate the "Science Stand" on a large scale. Although such aspects are desirable, our main interest is to produce knowledge that schools, non-formal educational spaces, municipalities, universities, and other institutions can duplicate at the local level.

The intervention methodology that we proposed follows Inquiry-Based Science Education (IBSE) methodology, understood as starting with the proposal of a problem to an audience, challenging them to wonder about a phenomenon or situation, and proposing some ways of investigating it in order to reach a satisfactory answer. The actual way in which IBSE can occur in our project depends on the situation, which presupposes different kinds of social interaction among participants, as mediated by exhibition resources. We defined some modalities of adopted actions, as shown in Table 5. Based on these modalities, we distinguished five basic levels of interaction, as described in Table 6. Finally, Table 7 illustrates the approximate prevalence of interaction levels to each modality of action.

Table 5. Modalities of action

Action	Public	Locations
Exhibition	General and School	Miscellaneous (events, etc.)
Presentation	School (Students and Teachers)	Universities
Intervention	School (Students and Teachers)	Schools
Training	Teachers and Students	Schools, Universities

Table 6. Levels of visitor interaction in exhibition activities

I	Handling	An experiment, panel, or any other exhibition element leads the individual visitor to manipulation, reading, or another form of direct action.
II	Monitoring	The visitor poses requests or questions about the exhibition, or an element that, by its own characteristics, requires monitored action. In this case, the interaction is triadic (visitor-monitor-element) and often involves small groups of participants.
III	Demonstration	A lecturer centralizes the attentions of an entire group around a given exhibition element, giving explanations, proposing activities, and asking questions.
IV	Activity	A whole group is asked to perform certain activities (individually or in groups), often with the use of consumable materials and eventually resulting in physical products that can be taken home by visitors.
V	Workshop	In this case, the activity is prescheduled. Participants are informed of the schedule in advance and are sometimes asked to bring certain materials. Workshops take longer and sometimes involve a systematic follow-up aimed at achieving minimum goals for all participants and/or an assessment of the process from the point of view of participants.

Table 7. Prevalent interaction levels for modalities of action

	Handling	Monitoring	Demonstration	Activity	Workshop
Exhibitions	●●●	●●	●		
Presentations	●	●●	●●●	●●	
Interventions		●	●●●	●●●	●●●
Trainings		●	●●	●●	●●●

Among the schools that visit or are visited by the “Science Stand”, we currently work with several fixed pilot schools in which one or more teachers directly integrate with the project team, attending regular meetings and developing, under our guidance, specific interventions. This structure not only allows the necessary evaluation of actions within the school space itself, but also enables the individual subprojects to find room for systematic research. We understand such actions as non-formal interventions in the school space (and other educational spaces), which is, by definition, a formal education environment. We are especially concerned about this interaction between non-formal and formal education as mediated by university-school relationships since it promotes several research possibilities. In the following, we detail some such instances.

LADYBUGS IN WONDERLAND: NON-FORMAL INTERVENTIONS

Based on our former experiences with science fiction and its possible uses for teaching science, we started doing research in this field as soon as we began to supervise graduate students (some undergraduate research was even brought in for the project). Our focus became a little broader than science fiction itself, extending to other similar cultural expressions, including several kinds of media and materials, all of which may be grouped under the more general term of “fantasy”. In short, we started a research line on fantasy studies applied to science education.

Fantasy narratives permeate education beginning in early childhood, from fairy tales to modern cartoons and feature films. They depict the natural and social world by means of fantastic representations of phenomena, beings, and situations, involving things as disparate as dragons, talking animals, magic, extraterrestrial beings, robots, enchanted forests, animated toys, and so on. Children build an important part of their worldview through those representations as found in books, puppets, games, toys, comics, films, and other media, including those related to nature and society. With the development of the graduate program on cultural studies at EACH-USP, we started to undertake systematic research in this area, seeking to investigate the relationships between the socio-political dimensions of science, the civilizing process, and child- and youth-oriented media as represented in the cultural industry products of audiovisual fiction, printed materials, and musical expression.

Given the parallel development of the “Science Stand”, we have made ongoing efforts to build connections between these two streams of research concerns. On the one side, we have our exhibition activities, which include playful experiments, handmade toys, and so on, and, on the other, extensive media materials, which – despite being interesting for science teaching – were not simple to configure in terms of the classical itinerant science center proposal.

In 2010, we obtained federal resources for our project “Reading Science”, allowing us to undertake research into the use of fictional works in the classroom. Initially, this work included such approaches as “Teaching the Theory of Relativity with Novels”, “Using Fantastic Tales to Teach Physics” or “The Use of Comics to Teach Science”, among others, which derived from master´s degree projects. We contend that the teaching of science should incorporate socio-cultural and political themes related to the sciences, including approaches to the arts and social sciences; the above proposals were directly related to that perspective. All of these works, however, concentrated mainly on analyzing certain materials and formulating possible didactic activities, with only occasional practical and systematic classroom applications.

For the results to be more effective, we decided to perform regular work to ensure organized data gathering, which led to two projects. The first one is called JOANINHA (Joy, Observe, Analyze, and Narrate: Inquiries on Nature, Humanities, and Arts), and intended for early childhood (between the ages of 2 and 6). It focuses on how children use literature, puppetry, toys, games, and play. Currently, it involves three kindergarten schools. The other project is ALICE (Arts and Playfulness in Inquiries into Science Culture in Educational Environments), and is directed toward pre-adolescent (tween) audiences It is intended for students 10-14 years-old, and is based on extra-curricular activities involving music, cinema, robotics, role playing, TV series, debates, and so on. We are presenting ALICE in two public schools. The acronym[5] JOANINHA spells out the Portuguese word for “ladybug”, a common figure in a variety of media and products targeted to early childhood. The second acronym refers to the well-known character from Lewis Carroll´s juvenile fantasy stories.

Our first systematic implementation took place in 2011, and utilized two undergraduate investigations which focused on illustrated children’s books and were directed towards younger children. These interventions occurred in public elementary schools, where we explored possibilities for, and educational applications of, children’s books, puppet theater, cartoons, and toys, among other resources. For example, we explored children’s books like “While Mummy Hen Was Away” (Young-So & Byeong-Ho, 2013) and “Rosie’s Walk” (Hutchins, 1971), which tell stories about hens leaving their chicken coops (or “homes”) and the chaotic results of their actions (a wolf threatening the hen’s eggs in the first one or a fox chasing the hen in the second one). By using books like these to address critical inquiries and to promote playful and didactic activities about such themes, we believe we can fulfill important goals in teaching science concepts, discussing social issues, and developing both language and artistic skills.

None of these books was written as a resource for teaching science, but, in reading them closely, and also as presented in puppet shows, a range of concepts could be explored, including the food chain, predator-prey relationships, and others that were less obvious, deriving from such questions as “Why does the hen live on the farm while the fox lives in the forest?”, “Why doesn’t the wolf stay in the forest? Isn’t there food him there? Why?” Or even “Is it true that when a hen leaves her home bad things always happen? Why?” Such simple questions may address environmental issues, animal rights, and gender relationships, among others.

Related activities involved text production, research, and the use of art and media for expressions of scientific content: panels, folders, paintings, performances, installations, videos, toys, music, fictional texts, among others. Secondary students produced and exhibited their work, not only in schools, but also in non-school settings, such as fairs, exhibitions, and other events. The team included graduate and undergraduate students from various courses.

The activities proposed in this scenario were intended to encourage primary and secondary students in critical observation of, and wonder about, the natural world, as well as to inspire students to think about social relationships and practices. For this to happen, we developed recreational activities for children that attempt to provide real opportunities for sociocultural interaction, while enabling contact with subjects related to science in connection with the humanities and arts. It was presented not as curricular content, but as an amusement intervention in the school context. The project as a whole included six fronts, performed by different teams, according to Figure 7.

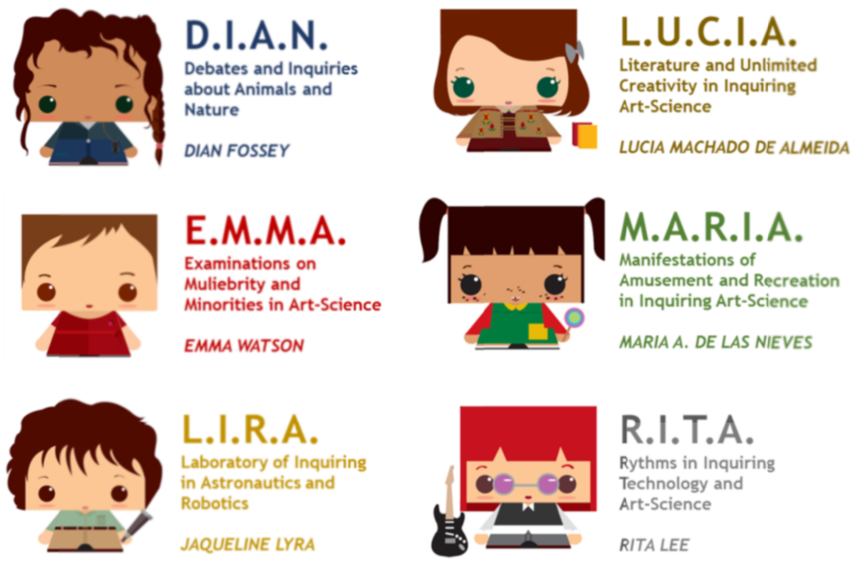

Figure 7. The six "Science Stand" intervention teams. Each one is called by an acronym honoring a woman whose work relates to the respective team proposal. (Illustration: Alina H. Paradiso, from the LUCIA team)

The names of the teams are references to prominent women: Dian Fossey, the zoologist and primatologist who was murdered for defending gorillas; Emma Watson, the actress and UN Women Goodwill Ambassador; Jacqueline Lyra, the Brazilian Aerospace Engineer at NASA; Lucia Machado de Almeida, the Brazilian writer of children's literature; Maria Antonieta de las Nieves, the Mexican children's comedian; and Rita Lee, the Brazilian rock star.

Because of the interdisciplinary character that we propose, any interested teacher can undertake these activities, regardless of their discipline or training, as may other school professionals whose expertise or interests can be integrated.

CONCLUSIONS AND RESEARCH DEVELOPMENTS

The "Science Stand", "JOANINHA", and "ALICE" projects, as well as the close interactions between the three, contribute to research on several fronts. We can split these into three main categories:

1. Questions about the production and strategies of science education/ dissemination. These questions involve reasoning about materials and messages and their effectiveness, in a broad sense.

2. Questions about the agents involved (school students and/or visitors, teachers, undergraduate monitors, graduate students). Here the focus is on educative interactions and on professional training.
3. Questions about the role of institutions and possible results for public policies in several instances, including extracurricular projects, science dissemination programs, university-school relationships, ongoing teacher training, and so on.

Therefore, our focus is not only on the children themselves. Beyond being based on work that is oriented toward children, the "Science Stand" program constitutes a professional training process and a laboratory in which to test possible educational policies on a micro scale. We consider the project as a study intended to contribute to public policies, not only in government instances, but also in the actions and roles of universities in society. The professional training process has two fronts: (a) in-service (and local) training, directed towards teachers' work in schools, and (b) initial training, since university students do most of the actual work as part of their professional training as teachers (or for other careers).

We cannot investigate or even discuss all of these possibilities in detail. Our objective here was simply to indicate that these developments are possible topics to address in future investigations. Therefore, we will focus a little bit more on the aspects we ourselves have been carefully dealing with for the last few years.

As far as the connections between "Science Stand" and JOANINHA/ALICE and where their possible mutual contributions are concerned, the main open question is how to integrate artistic and socio-political themes with the natural sciences in dissemination actions. Under that broader inquiry, this work provided some questions to address:

- How to offer, to the public, formats that assure relevant hands-on interactions with exhibitions based on suitable artistic and media materials?
- How to ensure the critical perspective and effectiveness of the intended message?
- How can we articulate new media products with classical exhibition artifacts without merely presenting a juxtaposition?
- How can we configure monitored actions to address the social issues of science through artistic and literary resources?
- What actions and products enable teachers to enjoy, incorporate, and adapt proposals in their teaching activities?

One of the goals of our various forms of research is to enable us to develop theoretical evaluation criteria for the didactic formulation process in this type of proposal. Since we often deal with people whose purposes are in principle not didactic, we understand that there are several aspects to be studied that are hardly addressed in the research on non-formal education and teaching, which is often focused on disseminating experiences, proposals, and possibilities. The three steps – analysis, formulation, and intervention – represented in the following scheme can properly summarize the roadmap we adopt to this approach:

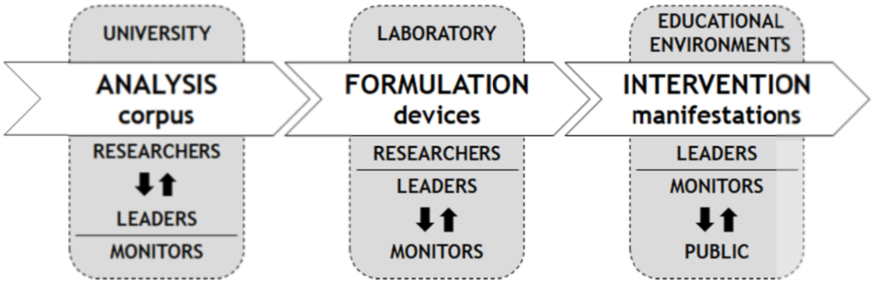

Figure 8. Roadmap to approaching media and arts products in science dissemination actions

One may consider, for example, that certain songs, movies or TV series could be used to approach a theme, such as the Space Race in the 1960´s, leading quite naturally to discussions about astronautics, rocket technology, the moon, life in space, and correlated social issues. Movies like “2001: A Space Odyssey” or “Barbarella”, TV shows like “Star Trek” or “I Dream of Jeannie”, and songs like David Bowie´s “Space Oddity” or Elton John´s “Rocket Man” come readily to mind. In this process, we are establishing a corpus of material that we consider to be useful to our purposes. The three-step process provides an iteration between what we want to teach or communicate and the products we consider satisfactory to doing so. This process eventually undergoes several reviews, with additions and cuts, which both limit and define the corpus.

The analysis process might be performed according to several paths, though we strongly concur with the idea that media and art products have their own logic and determination, and so recommend an awareness of the appropriate theoretical instruments for a given product. Specifically, we consider each product (such as a movie or a song) in at least three dimensions: text, discourse, and context. The first can be addressed by more specialized theoretical traditions, such as literary or cinema criticism, or via semiotics or content analysis. In general, a combination of one or more frameworks can highlight more interesting aspects than are noted when we restrict ourselves to just one. Discourse, in turn, is established as a relationship between the creator of the “speech”, the intentions implicit in it, and those who receive these messages. Many theoretical works on discourse analysis are available, and the decision as to which is more appropriate for a given work depends on the perspective of the researcher. The third dimension is that of the context, which we consider as the full picture of the social and historical situation which allows us to understand a specific work.

As far as the second step, formulation, is concerned, we should take into account the very concrete relationship that the chosen cultural product develops with the topics we want to explore. These parameters have a close dialogue with the previous analysis, but now we must be more specific in terms of teaching topics. Based on “2001: A Space Odyssey”, and on the general “Space Race” theme, we can explore conceptual topics, such as “explaining orbit”, or “the relativity of movements”, or “inertial and non-inertial reference frames”, or even “space artifacts and vehicles and their uses”. However, it is equally possible and desirable to consider topics about the nature of science, or the process of scientific knowledge production, which one may quite easily address based on the parts within the film plot in which the characters discuss a discovery under the moon’s surface. Does such a conversation have connections with the “Space Race” theme? Sure – after all, what is it space exploration for? We are free to ask such questions and to come to different conclusions. Space exploration, in principle, should give us clues about space, planets, and the laws of nature, as well as other related phenomena. Such question, however, could also lead us to other inquiries, such as “What were the actual goals of the space race?” As we know, that “race” was much more about politics than science. This refers to a third important source of teaching topics: the relationships between science and other social instances. In short, we think that there are at least three levels from which we can extract topics:

- The core of science and technology products (concepts, phenomena, conventions, artifacts, descriptions);
- The layer of the production of science processes, such as their history, their methods, their validation criteria, their instruments, and so on;
- Finally, an outer layer represented by the relationships that science establishes with other branches of human culture, such as politics, economy, religion, arts, etc.

It is important to point out that media and art products in particular have many possibilities regarding those two outer layers. As we know, the content of a given film or song (or something else in the cultural or media fields) is not necessarily or generally intended to teach science contents. However, it is very common for media and art products to depict views about science, scientific work, scientists, and their role in society. Such analyses, however, hardly end the processes of the second step. We have not yet planned what we should do with the public. If we choose a very well-analyzed song from a film, and extract some interesting topics from it, we must then think about what to do in order for people to best learn what we hope to teach. Will we exhibit the full movie and discuss it? Will we use a trailer or an excerpt, or posters, or reviews, or many things together? How will the audience interact with these things? Answering these questions is also a crucial part of the formulation step.

Finally, we should apply all these formulated didactics in a real situation. When we adopt the IBSE perspective, the strategy is to start from a question and then to develop the process from that initial inquiry. The goal of obtaining answers to people’s resulting queries derives from the motivation provided by the proposed situation. We can describe this process in three moments:

- The statement of a problem or a “mission” which participants must solve/fulfill, either individually or in groups depending on the activity’s nature.
- Participants are encouraged to find ways to solve their problems on their own, limited by certain previously-established rules.
- The disclosure of results (whose specific format varies, according to the activity, in order to allow the use of different languages), followed by systematization.

When we gather data to evaluate results and to produce conclusions for our research, we are interested, first, in checking if the introduction of media product activities, when compiled from the established parameters, encourages the interest of the participants in the debate, since such participation is the basis for this stage of the investigation. We perform observations using image and sound recordings in order to collect empirical results for the activities. These same recordings allow us to record the public’s behavior, as well as to verify whether the activities are effective in providing an environment of interest vis-à-vis the themes addressed in the activities. In our view, such records are a key requirement, allowing for later analysis of the quality of debate contents. They provide verification of attitudinal manifestations via observation of verbal and non-verbal language expressed by participants during activities, generally by means of photos, video recording, and note taking. From these, we can build protocol manifestation lists, such as exemplified in Table 8.

Table 8. Examples of participant’s attitudinal manifestations, as recorded in verifiable events for data gathering

• Demonstrates explicit and spontaneous interest in materials
• Makes positive (or negative) comments about the materials
• Discusses, in a spontaneous manner, the themes proposed
• Proposes issues not necessarily provided in the activity
• Establishes relations with other examples or situations
• Expresses conceptual questions
• Presents positions of social order, politics, ethics, or morals
• Mentions or suggests other materials on the proposed topic
• Requests more materials, in addition to those presented

We also believe that key research results should derive from the material work itself, so that the project foresees, at all stages, the systematization and dissemination of this material in such a way as to permit its reproduction and adaptation in other contexts. As regards participant teachers, discussing suggestions and proposals regarding activities and possible classroom results also integrates the dissemination effort to wider audiences.

NOTES

[1] http://www.fondation-lamap.org/
[2] Degrees in Natural Sciences, Environmental Management, Information Systems, Leisure and Tourism, Management of Public Policy, Physical Education and Health, Textile and Fashion, Gerontology, Marketing, and Obstetrics.
[3] http://www.museudavida.fiocruz.br/cgi/cgilua.exe/sys/start.htm?UserActiveTemplate=english&sid=269
[4] http://portalecoteca.blogspot.com.br/
[5] These acronyms were adapted for translation. In Portuguese, JOANINHA is "Jogar, Observar, Aprender, Narrar: Investigações sobre Natureza, Humanidades e Artes" while ALICE stands for "Arte e Lúdico na Investigação da Ciência nos Espaços Educativos".

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Luís Paulo de Carvalho Piassi
School of Arts, Science and Humanities
University of São Paulo (EACH)
São Paulo-SP, Brazil

Rui Manoel de Bastos Vieira
School of Arts, Science and Humanities
University of São Paulo (EACH)
São Paulo-SP, Brazil

Emerson Izidoro dos Santos
School of Arts, Science and Humanities
University of São Paulo (EACH)
São Paulo-SP, Brazil

VÍCTOR LÓPEZ AND ROSER PINTÓ

6. COMPUTER SIMULATIONS AND STUDENTS' DIFFICULTIES IN READING VISUAL REPRESENTATIONS IN SCIENCE EDUCATION

INTRODUCTION AND RATIONALE

Computer Simulations in Science Education

Computer simulations can provide learning opportunities in science education, allowing students to deal with virtual phenomena and to manipulate or modify parameters that would otherwise be impossible to observe. After the progressive introduction of computer simulations in school contexts over the last decades, there has been widespread scientific discussion about their impact in science teaching and learning. In this discussion, many questions have been raised related to educational impact, motivation effect, the role of feedback, the specificities of each scientific concept, modes of representation, and the relationship between real and virtual experiences (Chang, Chen, Lin, & Sung, 2008). In order to summarize this discussion, Smetana and Bell (2011) have carried out a critical review of 61 empirical studies published in journal articles, wherein scientific simulations are analysed as tools devoted to the promotion of content knowledge, science process skills, and conceptual change, among other aims. They found that the effectiveness of simulations is optimal in those cases where they are used as supplements (that is, not entirely replacing other instructional modes), when they include high-quality support structures, and when they promote student reflection and cognitive dissonance. In parallel, the review produced by Honey and Hilton (2011) indicates that most studies of simulations in the field of science education have focused on the conceptual understanding of students, providing promising evidence that simulations can advance this science learning goal. However, they also indicate that there is only moderate evidence of the impact of simulations on students' motivation. Finally, a third review made by Rutten, van Joolingen, and van der Veen (2012), analysing 510 Journal articles on the effects of simulations in science education, provides evidence that simulations can enhance traditional instruction, but also demonstrates that aspects such as teacher support and specific learning scenarios play an important role that has not been usually taken into account.

One of the most relevant and world-renowned online simulation repositories is the PhET platform (http://phet.colorado.edu/), which has delivered more than 100 million simulations to students in the last ten years, and received dozens of educational and scientific awards. PhET simulations aim to provide students with representations that allow them to develop deeper and richer understandings than

M. Pietrocola & I. Gurgel (Eds.), Crossing the Border of the Traditional Science Curriculum, 95–114.

they otherwise might do with text or static images. This is, for example, the case with the simulation called "Friction" (see Figure 1), which is intended to communicate the relationship between friction and heating. This simulation takes advantage of the combination of two complementary representations (Ainsworth, 2006), with representations of interaction at a macroscopic level (at the left side of the image, by one book on top of another) and at the molecular level (at the right side of the image, by two groups of particles vibrating and colliding, following a molecular-kinetic model), accompanied by a thermometer. When students interact with this simulation – by dragging one of the book surfaces – the vibration rate of the particles increases and, simultaneously, the temperature rises. Later on, if the surfaces remain static, the particle vibration rate decreases as (following an exponential cooling) does the temperature.

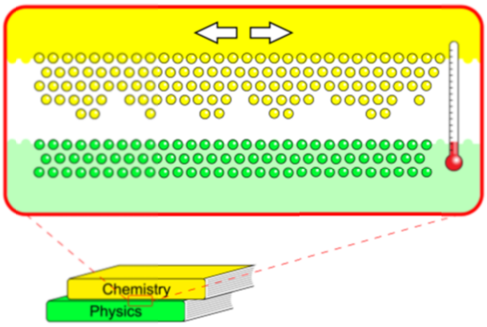

Figure 1. "Friction" simulation, representing the relationship between friction and heating. Available from http://phet.colorado.edu/en/simulation/friction

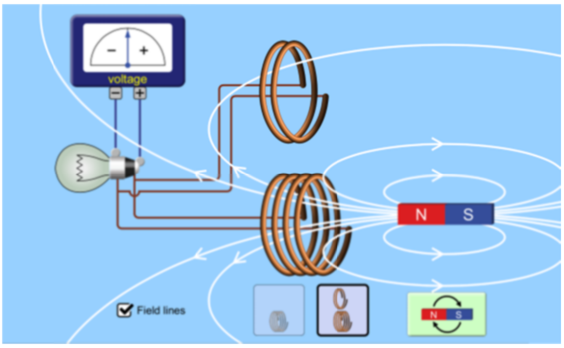

Figure 2. "Faraday's Law" simulation, representing electromagnetic induction. Available from http://phet.colorado.edu/en/simulation/faradays-law

Another PhET simulation intended for middle school students is named "Faraday's Law" (see Figure 2), and represents one of the many available online simulations addressing this physical phenomenon (Dega, Kriek, & Mogese, 2013). This simulation shows the electromagnetic induction produced in the interaction between a coil and a magnet that can be dragged around the screen by students. As its name makes clear, the simulation intends to communicate that the electric current – which is simultaneously represented by the illumination of the bulb and the movement of the needle of the voltmeter – is directly related to the variation of magnetic flux crossing the coil. Further, this simulation also allows students to observe a depiction of magnetic field lines. This simulation can be considered a highly interactive and dynamic representation that includes the three main types of change simultaneously, in their component graphic entities as defined by Lowe (1999): transitions, translations, and transformations.

Visualization of Simulations and Student Interpretations of Depicted Content

As PhET project members stated (Wieman, Adams, & Perkins, 2008), the desire of the authors of the simulations – as with, in principle, any other educational simulation – is to bring scientific concepts to students in the most comprehensible fashion possible. For this reason, the two previously-presented simulations include a full complement of visual resources and features, such as interactivity (draggable objects), dynamism, multiple representations, richness of colour, and/or representations of invisible and abstract entities (whether particles of matter or magnetic lines).

Nevertheless, despite the desire of the authors for easily-comprehensible simulation designs, we assume that there is a gap between what students visualize and how students might interpret visualized information. This gap results from a wide variety of perceptive and cognitive mechanisms that may lead to misunderstanding. When visualizing a simulation, students not only need to identify all the visual elements and their most important features, but also to decode the visual grammar of the depicted representations, and to relate that visual grammar to meaning, and then, accordingly, to construct the conveyed message (Kress & van Leeuwen, 1996). In this sense, previous studies have refuted the assumption that when students read a visual representation they correctly understand its meaning. Studies in the field of Science Education by Ametller and Pintó (2002), Colin, Chauvet, and Viennot (2002), and Stylianidou and Ogborn (2002) demonstrated that most visual representations can inadvertently convey wrong ideas to students, especially when there is a lack of student knowledge of the visual language. Furthermore, the benefits of the visual communications offered by simulations, as well as their risks and challenges in the field of science education, are still an open question (Norris, 2012; Phillips, Norris, & Macnab, 2010; Treagust & Gilbert, 2009; Treagust & Tsui, 2013).

Outside the scope of science education literature, visualization as a cognitive mechanism has received much attention in the fields of graphics comprehension and instructional design. Among the several elements affecting visualization, it is well known that the prevalence and the attention given by the reader to each visual element play an important role (Larkin & Simon, 1987; Winn, 1994), as are the representational connections that each reader is able to make in his/her memory (Schnotz, 2004). The dynamic, multimedia, interactive nature of simulations can both enhance and hinder student interpretations of depicted content, even when learners have sufficient cognitive resources to perceive and process all of its essential information (Mayer & Moreno, 2003; Sweller, Van Merriënboer, & Paas, 1998). The 26 primary studies reviewed by Höffler and Leutner (2007) showed an instructional advantage of animation over static images, especially when animations are representative rather than decorative. Nevertheless, misinterpretations can still be accentuated due to the constraints imposed by the limited sensitivity of the learner to dynamic information (Meyer, Rasch, & Schnotz, 2010), and also because of the tendency by the student to extract the most perceptually-salient animated information, instead of the most relevant information (Lowe, 2003). Something similar occurs when students have to pay attention to different sources of information that act as multiple representations (Ainsworth, 2006), where the prior knowledge of the student affects the split of their visual attention, whether on conceptually relevant features or on superficial features (Cook, Wiebe, & Carter, 2008). These and other questions have led to deep discussions about empirically-validated design factors and principles for effective educational simulations, as well as the translation of these factors and principles in science education instructional design, some of which can be found in Cook (2006) or Plass, Homer, and Hayward (2009).

Students' Explanations of the Scientific Content of Simulations

Given the gap between visualization and interpretation by students, if a group of middle school students with a low prior knowledge of the domain visualizes one of the two previously presented simulations – "Friction" and "Faradays' Law" – we wonder if students' full understanding of the depicted scientific concepts should be taken for granted at all. In fact, when speaking of "understanding", we refer to conceptual understanding as widely discussed in the field, which other authors have called conceptualization (see, for instance, the definition of this term proposed by Linder, 1993). However, this debate remains beyond the scope of this study and, indeed, we assume that the only way to identify students' understandings is by means of their oral / written explanations, that is, by observing how students respond when asked about any specific simulation content (i.e., "What do you think this simulation is trying to tell you?"). For this reason, our focus will be on student explanations, which, according to the previously-mentioned studies, may differ somewhat from the scientific explanations that the simulations intend to communicate.

In order to address the analysis of these student explanations, it is also necessary to take into account students' previous knowledge about the domain and, more specifically, its associated alternative ideas (Gunstone, 1989; Pozo & Gómez, 1998), many of which bear erroneous science implications and which have received considerable attention during previous decades. Considering the "Friction" simulation, most of its depicted scientific concepts have several associated alternative ideas that have been widely reported in the literature. This is the case with the particle-based representation of matter that appears in this simulation, which we can easily associate with different alternative ideas about particles and matter, such as the connection of macroscopic properties to microscopic particles (Harrison & Treagust, 2002; Lijnse, Licht, de Vos, & Waarlo, 1990), or the idea that solids are not made up of atoms, especially those without visible granularity (Johnson, 1998; Nakhleh, Samarapungavan, & Saglam, 2005; Nakhleh, Samarapungavan, Saglam, & Duru, 2006), or the notion that atoms and molecules are embedded in matter (Griffiths & Preston, 1992; Johnson, 1998; Renstrom, Andersson, & Marton, 1990). Similarly, concerning the relationship between particle behavior and temperature displayed in the simulation, different related alternative ideas have also been identified, such us the view that the particles in a solid are not moving (Lee, Eichinger, Anderson, Berkheimer, & Blaskeslee, 1993; Novak & Musonda, 1991), or the idea that the average speed of the atoms or molecules in a substance remains the same with a change in temperature (AAAS, 2013). The "Friction" simulation also includes other scientific topics, such as the cooling processes of matter, which in turn may entail alternative student conceptions. For instance, students may assume that when a body is cooled its temperature tends to reach a "natural" temperature (Wiser, 1995).

A range of associated alternative ideas can also be highlighted as regards the scientific concepts depicted in the "Faradays' Law" simulation. On the one hand, we should consider the variety of alternative ideas about electric current and electrical circuits (Cosgrove, Osborne, and Carr, 1985), such as the attenuation model or the unipolar model (Driver et al., 1994; McDermott & Shaffer, 1992; Shipstone, 1988), as well as the idea that electric current moves sequentially across the different elements of a circuit (Closset, 1983; Holton & Verma, 2011; Psillos, Koumaras, & Valassiades, 1987). On the other hand, we should also consider those alternative ideas which regard electromagnetic induction and interactions between magnets and coils, such as the difficulties inherent in conceiving the coil-magnet interaction as a distance interaction (Guisasola, Almudi, & Zuza, 2013; Thong & Gunstone, 2008), and in distinguishing between magnetic field, magnetic flux, and variations in magnetic flux (Albe, Venturini, & Lascours, 2001; Maloney, O'Kuma, Hieggelke, & Van Heuvelen, 2001), not to mention the lack of physical meaning given to electromagnetic induction (Mauk & Hingley, 2005; Thong & Gunstone, 2008). Finally, concerning the magnetic lines depicted in this simulation, different alternative ideas on the parts of students have also been identified, such as the idea that magnetic lines correspond to "real" entities (Thong & Gunstone, 2008).

Finally, beyond students' specific alternative ideas related to the scientific content of the two previous simulations as presented, student explanations can also be influenced by more general psychological mechanisms. In fact, the ways in which these alternative ideas are linked to forms of normal or spontaneous reasoning in everyday life and everyday experience – and assumed by students prior to receiving any teaching on the subject – have been widely studied. These mechanisms have received considerable attention through various approaches, such as the "spontaneous reasoning" framework (Viennot, 1979), the "phenomenological primitives" framework (diSessa, 1983), and the "psychology of common sense" framework (Pozo, Sanz, Gómez, & Limón, 1991). They have also been identified in the psychology subfield of graphics perception, when describing mechanisms for reducing the cognitive load in visualizations (Paas et al., 2004; Schnotz, 2005; Sweller et al., 1998).

RESEARCH OBJECTIVES AND METHODOLOGICAL APPROACH

In this context, the objectives of our research are:

- To identify the explanations that 14-16-year-old students give when they are asked about the scientific meaning of the two simulations, "Friction" and "Faradays' Law".
- To compare these explanations with the expected/intended scientific explanations of the simulations.
- To identify which reasoning mechanisms might be involved in these student explanations.

In order to achieve these objectives, we followed several steps. The two simulations previously presented (Figures 1 and 2) were selected according to a variety of educational criteria, including the adequacy of the scientific content of the simulations for the school curriculum for this age group, the level of interaction provided by the simulation, and the absence of any mathematical formality that would hinder student understanding. Then, a set of statements was defined, corresponding to the scientific explanations that resulted from a content analysis of the two simulations, as well as the pedagogical aim of each simulation as outlined in the PhET website. The ensemble of defined statements is presented in Tables 1 and 2, wherein each table links the scientific concepts that constitute the conceptual system of each simulation.

Later on, we selected a group of 20 students (14–16 years old) from four different schools in the Barcelona area. All of the students had some prior knowledge about the scientific topics in question, but none of them were experts on either subject. We then carried out two sets of interviews, one for the "Friction" simulation and another for the "Faraday's Law" simulation, with a group of 10 students per simulation. We used the ten first letters of the alphabet (from A to J) to select the ten students interviewed about "Friction": student A, student B, … student J. Similarly, we used the following ten letters (from K to T) to name the students interviewed about "Faraday's Law": student K, student L, … student T. All interviews were individual and semi-structured, and included questions about the scientific meaning of the simulations. Each interview took about 20 minutes, and was video-recorded and transcribed.

At this point, we selected the fragments of interviews where any student explanation could be identified. Later, we coded and classified all of these fragments by comparing the similarities and differences between student explanations and the scientific explanations that the simulations were intended to communicate, with a particular focus on those explanations that differed from the scientific explanations (Table 3). Finally, we discussed the reasoning mechanisms that might be involved in those student explanations that differed from the scientific explanations, according to the different frameworks presented above.

Table 1. Summary of the scientific explanations that the "Friction" simulation is intended to communicate

Code	Statement
Fric1	Friction between two surfaces produces a temperature increase of the rubbed surfaces.
Fric2	The macroscopic friction between surfaces corresponds to the microscopic collisions between particles.
Fric3	Collisions between particles increase the vibration rate of the particles.
Fric4	The temperature increase (decrease) of the rubbed surfaces can be microscopically explained by the increase (decrease) in the vibration of particles.
Fric5	When surfaces stop rubbing, the previously-increased temperature decreases because of the difference with the temperature of the environment.
Fric6	The cooling rate of the rubbed surface follows an exponential rate, decreasing very rapidly at the beginning and then progressively slowing down.
Fric7	As well as increasing temperature, friction also causes some particles to break away, producing erosion on the rubbed surfaces.

Table 2. Summary of the scientific explanations that the "Faradays' Law" simulation is intended to communicate

Code	Statement
Fara1	The movement of the needle of the voltmeter indicates the voltage between the ends of the coil.
Fara2	The intensity of the bulb's light is directly proportional to the absolute value displayed by the voltmeter, and both the illumination and the needle's movement are simultaneous.
Fara3	Magnetic lines represent the direction and the intensity of the magnetic field.
Fara4	When the magnet moves close to the coil, electric current is induced. The intensity of the current depends on the number of magnetic lines crossing the coil.
Fara5	The induced electric current depends on the position and the velocity of the magnet.
Fara6	The induced electric current depends on the number of turns in the coil.

Overall, this methodological procedure is qualitative, since we are performing a diagnostic study intended to reveal which student explanations differ from scientific explanations, and also investigating which reasoning mechanisms might be involved. By contrast, the study is not focused on the quantitative prevalence of these student explanations and reasoning mechanisms.

ANALYSIS OF DATA AND RESULTS

Analysis of Students' Explanations Regarding the "Friction" Simulation

As stated above, the ten students (A to J) who were asked about the "Friction" simulation had to answer a set of questions about the scientific content of the simulation, that is, about the behavior of the particles, the relationship between friction and heating, and also about the behavior of the thermometer. The wide variety of explanations given by students was classified according to which of the scientific concepts were involved in each explanation, using the classification presented in Table 1.

The first of these statements, Fric1, "Friction between two surfaces produces a temperature increase of the rubbed surfaces", can be considered the main scientific explanation behind the depicted information of the simulation. Nevertheless, despite the relevance of this explanation, two alternative explanations were given by students. First, some students explained that the increase in temperature was produced by simple contact between surfaces <Fric1-SE1>, and not necessarily by the friction (movement) between these surfaces. This explanation could be identified in expressions such as "*When I join the two books, they get heated*" [Student A], and also "*The books are heated because of their contact*" [Student B]. Another student explanation differing from the scientific explanation Fric1 was supported by a simplified and naive heat-transfer model, and held that the increase in temperature is produced by "temperature transfer" <Fric1-SE2>. This explanation can be found in statements by students such as "*Each book has its own temperature. When you join them, they take on more temperature*" [Student D].

A second piece of relevant information depicted in the simulation is Fric2, "The macroscopic friction between surfaces corresponds to the microscopic collisions between particles", an idea that links macroscopic phenomena with particle-based interpretation. However, some students did not link these two pieces of information because they were only focusing their attention on the right side of the picture. This led them to explain the behavior of the system as related to two isolated groups of particles, without any integration with the rest of the picture <Fric2-SE1>. This is the case, for instance, in explanations like "*I can see an isolated group of atoms (…) Oh, the books! I hadn't noticed the books*" [Student B].

A deep understanding of the "Friction" simulation implies a conceptual understanding of the role of particle collisions, since these collisions are the actual cause of the increase in the vibration rate of particles, and, so, the temperature increase. For this reason, we defined Fric3 as "Collisions between particles increase the vibration rate of the particles". Nonetheless, the idea of particle collisions did not appear in some student explanations, and was in fact substituted by other physical explanations. We found, for instance, references to a chemical reaction <Fric3-SE1> such as, "*It looks like a chemical reaction*" [Student A]. Other explanations were based on the idea of a change of state <Fric3-SE2>, which includes explanations with terms such as "*evaporation*" or "*melting*". This is the case of "*It turns from solid to liquid*" [Student J]. Finally, a third explanation that differs from the idea of particle collisions is based on the idea of the mixture of substances <Fric3-SE3>, which was identified in expressions like "*Green particles got mixed with yellow particles*" [Student C].

To supplement the previous statement, we defined Fric4 with the micro-macro relationship of temperature: "The temperature increase (decrease) of the rubbed surfaces can be microscopically explained by the increase (decrease) in the vibration of particles", which represents the basis of the kinetic particle theory. This idea did not appear in some students' explanations, which suggests that they did not understand the relationship between particles and temperature <Fric4-SE1>: "*I don't know the relationship between particles and the thermometer*" [Student E]. Other alternative explanations can be found in the inverse causality of the relationship between macro and micro levels <Fric4-SE2>, such as "*The temperature rises and, for this reason, particles begin to vibrate faster*" [Student C]. That is, instead of explaining the temperature as the macroscopic consequence of the increase of vibration rate, Student C explained the increase of vibration rate as the consequence of temperature increase.

After the book has been moved/rubbed (dragged), if it is then left in place (dropped), a decrease in the vibration rate of the particles can be observed in the simulation. This decrease in vibration rate is accompanied in the simulation by a decrease in temperature, which is intended to show that any heated material is later cooled if the environmental temperature is lower than its temperature. For this reason, we defined Fric5 as "When surfaces stop rubbing, the previously-increased temperature decreases because of the difference with the temperature of the environment". In fact, most of the students were able to explain the cooling in terms of the stopping of friction, as indicated in Fric5. However, two students identified the separation between the two surfaces as the cause of the cooling <Fric5-SE1>. This is, for instance, the explanation found in "*[The temperature decreases] because the bodies are not together any more, and for this reason they get colder*" [Student D].

In parallel, according to Newton's law of cooling, the rate of increase or decrease in the temperature of any material depends on the temperature difference between this material and the environment. For this reason, Fric6 was defined as "The cooling rate of the rubbed surface follows an exponential rate, decreasing very rapidly at the beginning and then progressively slowing down". Contrary to this idea, some of the students explained cooling in terms of a constant rate of temperature decrease <Fric6-SE1>. An example of this type of answer is "*The decrease in the temperature is the same all the time*" [Student E].

A final idea presented in the "Friction" simulation concerns the erosion of surfaces. When students interact with the simulation by rubbing the book (that is, dragging or shaking it), it can be observed that some particles break away from their position and come out of the representation. That is why Fric7 was defined as "As well as increasing temperature, friction also causes some particles to break away, producing erosion on the rubbed surfaces". Not all students interpreted this representation as an erosion phenomenon, and different alternative explanations arose. Some students explained the breaking away of some particles as if it were the evaporation of the material <Fric7-SE1>: "*at a certain point, some particles* *are evaporated and they come off*" [Student H]. Other students explained this breaking away as the particles being part of the air comprised between the two surfaces <Fric7-SE2>: "*These [particles] are air's atoms in the middle [of the two books]*" [Student F].

Analysis of Students' Explanations Regarding the "Faraday's Law" Simulation

The second group of students were asked about the scientific content of the "Faraday's Law" simulation: the idea of the electric circuit, electromagnetic induction, the behavior of the bulb, and the behavior of the voltmeter, including its relationship with the magnet, etc. In the following, we analyse the variety of explanations given by these ten students (K to T) on the basis of the six statements presented in Table 2.

As stated above, the "Faraday's Law" simulation intends to explain that the movement of a magnet around a coil produces an induced voltage – and therefore, an induced electric current – in a circuit. Thus, the representation of this induced voltage should be correctly interpreted by students. In the case of this simulation, voltage is represented by the needle of the voltmeter as well as by the illumination of the bulb. For this reason, we defined Fara1 as "The movement of the needle of the voltmeter indicates the voltage between the ends of the coil". According to their answers, not all the students achieved a correct understanding of this representation. On the one hand, some students explained the behavior of the needle and its back-and-forth motion as a switch that opens and closes the circuit <Fara1-SE1>. This explanation can be observed in statements such as "*This [the needle] is a switch that keeps changing all the time*" [Student L]. On the other hand, other students explained the role of the voltmeter as a sensor that makes measurements directly on the magnet, and not on the coil <Fara1-SE2>: "*it [the voltmeter] measures the force of the magnet, and this is positive or negative because of the poles*" [Student N].

In parallel to the movement of the voltmeter needle, the other source of information that allows students to understand the induced voltage is the illumination of the bulb. The simulation intends to communicate that both phenomena (needle movement and bulb illumination) are simultaneous and directly related; that is, the more illumination, the more the needle moves to the left or to the right. For this reason, we defined Fara2 as "The intensity of the bulb's light is directly proportional to the absolute value displayed by the voltmeter, and both the illumination and the needle's movement are simultaneous". This scientific explanation differs from some of the students' explanations. Some students described the different phenomena of the simulation in successive order, one after another <Fara2-SE1>, according to the common misconception identified in the literature by which understanding electric current runs sequentially through the circuit elements (Driver et al., 1994; Shipstone, 1984, 1988). This explanation could be identified in expressions such as "*When the magnet moves, [the electric current] first goes to voltmeter, and then it moves to the bulb*" [Student L]. A second alternative explanation given by students consisted in relating the illumination of the bulb only with the positive voltage, but not with the negative voltage <Fara2-SE2>. This explanation appeared, for instance, in the expression "*When it [the voltmeter's needle] is in the positive side, [the bulb] is illuminated but when it [the needle] is in the negative, no*" [Student K]. This explanation is in line with the alternative explanation identified by Holton and Verma (2011).

Another key concept behind the "Faraday's Law" simulation is the idea of magnetic field, which appears as represented by magnetic lines. For this reason, we defined Fara3 as "Magnetic lines represent the direction and the intensity of the magnetic field". Nevertheless, some students gave alternative explanations. First, some students explained that the represented lines were the movement of electrons <Fara3-SE1>, as suggested by the statements "*This represents the direction taken by electrons*" [Student P] and "*The lines through which electrons travel*" [Student S]. Other students' explanations suggested that magnetic lines were physical entities that could collide against real objects <Fara3-SE2>, as suggested by statements such as "*lines collide with the coil*" [Student K]. In fact, this specific conception has also been identified in previous studies (Thong & Gunstone, 2008). Finally, we identified a third student's explanation according to which magnetic lines correspond to the perimeter of the field <Fara3-SE1>, indicating a notion of the magnetic field as finite and delimited by an elliptical line, that is, a perimeter. We identified this explanation when we observed one student [Student R] mentioning the idea of "*inside the field and outside the field*" as referring to the area inside and outside of the ellipse formed by one of the magnetic lines.

While the three previously defined statements Fara1, Fara2 and Fara3 focus on the separated ideas of electricity and magnetism, the next three statements address the idea of electromagnetic induction. First, Fara4 states that "When the magnet moves close to the coil, electric current is induced. The intensity of the current depends on the number of magnetic lines crossing the coil". The highly complex idea of electromagnetic induction was not used by some of the students; instead, alternative explanations were given, supported by the idea of a physical interaction between the magnet and the coil. This result agrees with results given by Guisasola, Almudi and Zuza (2013), which show that interaction at a distance between a coil and a magnet is not easily conceived by students. This alternative idea appeared in student interviews through two different explanations. In two interviews, students explained that the circuits were opened because there was a hole in the middle (the coil), and that the magnet was then connected inside the coil, closing the electric circuit and allowing electric current to flow <Fara4-SE1>. This explanation can be observed in "*Now, [when the magnet is exactly inside the coil] the circuit is closed, you know? At this moment, electrons are able to freely move through the circuit*" [Student O]. Another alternative explanation given by students was based on the physical contact (and even friction) between the coil and the magnet <Fara4-SE2>. This is the case in quotes such as, "*When the magnet touches the coil, the bulb lights because it [the magnet] transfers positive or negative energy to the bulb*" [Student S], and also "*When the magnet contacts the magnet, there are micro-crashes with electrons. It generates electricity*" [Student P]. This last student also stated later that the more friction, the more electric current was produced, demonstrating an alternative idea also identified by Driver et al. (1994).

Since Faraday's law of induction states that the induced electromotive force in any closed circuit (in our case, a coil) is equal to the negative of the time rate of change of the magnetic flux through the circuit; Fara5 indicates that this time rate of change in magnetic flux depends on the position and the velocity of the magnet. Since magnetic flux is a complex concept for 14–16-year-old students, the statement was simplified as "The induced electric current depends on the position and the velocity of the magnet". Despite this, some students' alternative explanations did not describe the electric current in terms of the velocity of the magnet. They related the intensity of the electrical current only with the position of the magnet, but not with its velocity <Fara5-SE1>. Some students described the behavior of the system in terms of the position of the magnet, using expressions like "*If the magnet is closer the electricity is bigger*" [Student N]. However, in these explanations they did not explain that if the magnet remained still, no electric current was induced. Another explanation given by students assumed that electric induction occurred when the magnet moved, but that the induced electric current had a constant value that did not depend on the velocity of the magnet <Fara5-SE2>. This is the case of Student L, who was moving the magnet with different velocities when he said "*I always perceive the same light intensity*".

Finally, according to Faraday's law of induction, the last statement, Fara6, has been defined as "The induced electric current depends on the number of turns in the coil". This idea is represented in the simulation through the existence of two different coils with a different number of turns (two and four, respectively). Two different alternative student explanations for this idea were identified through the interviews. First, we identified an explanation that stated that the induced current depended on the length of the coil, but held that this length was not related to the number of coils, but rather with the time that the magnet remained inside the coil when it was crossing it <Fara6-SE1>. This explanation was observed when Student L hypothesized that "*Since this coil is longer, there is more electricity passing because the magnet remains longer inside the coil. And if it [the coil] is shorter, there is less light*". Other students were also not able to adequately relate the number of turns of each coil with the induced current, as they stated that this number did not affect the induced current <Fara6-SE2>. To wit, "*it doesn't matter which coil crosses the magnet. The bulb lights in the same way*" [Student Q], a statement that was later amended ("*Well, with the second coil the intensity is greater, but I hadn't realized it before*").

Summary of Students' Alternative Explanations

The ensemble of alternative explanations given by students is summarized in Table 3. For simplicity, the table does not include student quotes verbatim, but instead gives a brief description of the idea underlying student explanations, as well as identifying which student gave each explanation.

Table 3. Summary list of students' alternative explanations

Code	Code'	Brief description of the student explanation	Student
Fric1	Fric1-SE1	the increase in temperature is produced by simple surface contact	A,B
	Fric1-SE2	the increase in temperature is produced by "heat transfer"	D
Fric2	Fric2-SE1	the image only represents two isolated groups of particles	A,B,G
Fric3	Fric3-SE1	the image represents a chemical reaction	A,C
	Fric3-SE2	the image represents the melting of a solid	D,J
	Fric3-SE3	the image represents a mixture of substances	C,D
Fric4	Fric4-SE2	there is no relationship between particle behavior and temperature	E,I
	Fric4-SE2	the increase in particle vibration is caused by the increase in temperature	C,E,F
Fric5	Fric5-SE1	the cooling is caused by the separation of the surfaces in contact	A,B,D
Fric6	Fric6-SE1	the cooling of the surface occurs at a constant rate	A,B,D,E,I,J
Fric7	Fric7-SE1	the particles coming off correspond to an evaporation process	D,H
	Fric7-SE2	the particles coming off correspond to air particles	F
Fara1	Fara1-SE1	the voltmeter is a switch that opens and closes the circuit	L
	Fara1-SE2	the voltmeter measures "magnetic force" directly	N
Fara2	Fara2-SE1	situations happen in succession, one after another	L,M
	Fara2-SE2	the bulb only lights with positive voltage, not with negative	K,M
Fara3	Fara3-SE1	the lines represented the movement of electrons	R,S
	Fara3-SE2	magnetic lines are physical entities that collide against real objects	K
Fara4	Fara4-SE2	when the magnet "connects" inside the coil, the circuit gets closed	O
	Fara4-SE1	Electromagnetic Force is produced by physical contact/friction between the coil and magnet	K,M,P
Fara5	Fara5-SE1	EMF depends on the position of the magnet, but not on its velocity	K,M,N,P,T
	Fara5-SE2	EMF is constant, therefore it does not depend on the velocity of the magnet	L
Fara6	Fara6-SE1	EMF depends on the length of the coil but not on the number of turns	L
	Fara6-SE2	EMF is the same regardless of the number of turns of the coil	Q

According to Table 3, a wide variety of alternative explanations can be identified when students are asked about the science concepts in these simulations. It is important to highlight that the variety of explanations involves both the range of specific concepts for which each explanation concerns, as well as the set of alternative explanations that each student gives about each concept. For example, in the "Friction" simulation, we have not only identified alternative explanations concerning a variety of concepts (friction, temperature, work and heat, the micro-macro relationship, the molecular-kinetic model, etc.), but also a variety of explanations concerning a specific concept, as happens for Fric3. In fact, with only a small number of students (ten students per simulation), there were 12 alternative explanations for the "Friction" simulation – out of which ten were used by two or more individual students – and, in the "Faraday's Law" simulation, 12 alternative explanations were identified – out of which five were stated by two or more students. As regards the recurrence of the different students' answers, it is important to remark that alternative explanations concerning all the defined statements have been identified. They include not only those complex or abstract concepts which might seem more difficult for students (as in, for instance, a deep understanding of the relationship between the vibration of particles and the idea of temperature), but also the ideas at the core of the information depicted in the simulations, as occurs with Fric1 ("Friction between two surfaces produces a temperature increase of the rubbed surfaces"), which, a priori, might seem relatively simple and easy for students.

Discussion of Students' Underlying Reasoning Mechanisms

Considering the expected scientific explanations that should result from the content analysis of the two simulations (that is, the statements defined in Tables 1 and 2), and comparing them with students' alternative explanations given during their interviews, a set of commonalities can be identified. These commonalities cannot, however, be considered as the sole causes of students' alternative explanations (Meltzer, 2007); we thus refer to the reasoning mechanisms by which alternative ideas arise which may be implicit in such explanations. They have been grouped according to the literature (diSessa, 1983; Leinhardt, Zalavsky, & Stein, 1990; Pozo et al., 1991; Pozo, 1987, 1993; Viennot, 1979, 1996).

A first commonality identified in students' explanations concerning both simulations is the description of the behavior of the simulation in terms of the state of their elements, and not on the processes depicted. This is the case of Fric1-SE1, "the increase in temperature is produced by simple surface contact", and Fric5-SE1, "the cooling is caused by the separation of the surfaces in contact". This reasoning can also be observed in the answers about the relationship between the coil and the magnet in the "Faradays' Law" simulation: Fara4-SE1, "when the magnet "connects" inside the coil, the circuit gets closed"; Fara4-SE2, "EMF is produced by physical contact/friction between the coil and magnet"; and Fara5-SE1 "EMF depends on the position of the magnet, but not on its velocity". All of these explanations are based on the position of the objects (whether the book or the magnet) but not on the movement of these objects. Students are able to describe the behavior depending on whether the books (or the magnet and the coil) are "in contact / not in contact", but not on whether they are "moving / not moving". Actually, this finding agrees with the results of Gustafson and Mahaffy (2012), which state that students tend to explain the behavior of particles in terms of their position and not of their movement. This reasoning mechanism can be considered a simplification of the total information depicted in the simulation, since students are focused on the position of the visual objects, which is an easier perception, and not on their movement.

Something similar occurs with Fara5-SE2, where "EMF is constant, thus it does not depend on the velocity of the magnet", and with Fara6-SE2, "EMF is the same regardless of the number of turns of the coil". In these two explanations, students distinguish whether the bulb lights or not, but they do not discern the different values of more or less illumination, that is, the different degrees of intensity. This leads to a discretization of the displayed variables, similar to the mechanism reported by Driver et al. (1994), where students did not see motion as belonging to a number of different categories, such as at rest, constant velocity, speeding up, slowing down, changing direction, etc. Instead, they saw motion as simply moving or not moving. Furthermore, this result also agrees with students' natural tendency to interpret continuous data as discrete data (Leinhardt et al., 1990). On further analysis of Fric6-SE1 "the cooling of the surface occurs at a constant rate", a similar simplification mechanism can also be identified. In the previous cases, students had understood a movement-dependent behavior as a position-dependent behaviour; similarly, in this case students explained a non-linear behavior as a linear behavior, that is, a linearization mechanism. This also agrees with historical results regarding the tendency toward interpreting non-linear graphics as linear graphics (García, 2005; Markovitz, Eylon, & Bruckheimer, 1986).

In parallel to these simplification mechanisms, students also tend to fill their explanations with stored memory information, that is, with more-accessible long term memory knowledge. This implies the necessity of changing the information offered by simulation images to information that is closer to "reader" minds, according to the accessibility rule defined by Pozo et al. (1991). On analyzing some of the students' answers, a common denominator can be identified: students usually introduce scientific concepts which are not related to the simulation, but to something learned shortly before they were interviewed. For the "Friction" simulation, two references to changes of state can be identified: Fric3-SE2, "the picture represents the melting of a solid" and Fric7-SE1, "the particles being removed correspond to an evaporation process"; in both cases, students had previously studied the molecular-kinetic model for explaining changes of state in their classes. For the "Faradays' Law" simulation, both Fara1-SE1, "the voltmeter is a switch that opens and closes the circuit", and Fara4-SE1, "when the magnet "connects" inside the coil, the circuit gets closed", refer to the idea of an opened / closed electric circuit; this idea had been studied by students some weeks before the interview. Students' tendency to deal with their misunderstanding of simulations by including concepts retrieved from accessible memory had also been reported by Genover, Pozo, and Vilar (1998), who identified how students substitute the information from a text with other general knowledge they possess. This reference to previous, accessible knowledge can also be identified in those explanations where students used other scientific models to explain phenomena: In

Fric1-SE2, “the increase in temperature is produced by “heat transfer”, is arrived at by substituting a model of work with a model of heat. In Fara5-SE2, “EMF is produced by physical contact/friction between the coil and magnet”, a mechanical model is used in place of an electromagnetic model, as Driver et al. (1994) had identified. Even the students’ explanation found in Fara3-SE1, “the lines represented the movement of electrons”, arose because they have studied electricity (but not magnetism) in their science classes.

A last kind of commonalities in students’ answers can be identified in those cases where students reorganized the information depicted by the simulations, modifying relationships between elements in terms of causalities and interactions. This is the case, for example, in the associations that some students made about the spatial contiguity between the magnet and the voltmeter (Fara1-SE2), as well as between the bulb and the magnetic line (Fara3-SE2). This association of ideas has been described by Pozo (1987) as a conceptual relationship being imputed to a visual relationship. This organization of information in students’ explanations can also be seen when students explain different phenomena that are simultaneous as occurring in a successive order. This is the case in Fara2-SE1, which clearly corresponds with the spontaneous sequential reasoning identified in the literature (Closset, 1983; Viennot, 1996); and in the inversion that can be identified in Fric4-SE2, where, first, temperature rises and then particles increase their vibration rate. Finally, in the reorganization of information that students make in their explanations, they occasionally directly eliminate a part of the depicted information. This is the case in Fric2-SE1, where three students tried to explain the system as if there were no books in the left side of the picture, and also Fara2-SE2, where one student tried to explain the behavior of the bulb as if there were no illumination when the voltmeter indicated negative values.

CONCLUSIONS AND IMPLICATIONS

The identification of this array of alternative student explanations suggests that representing scientific concepts through simulations that have been specially designed for middle school students does not automatically lead to the correct understanding of these concepts on the part of those students. Thus, these findings lead us to refute the implicit conception that sometimes underlies teacher’s and designer’s assumptions, that visualizing the images displayed in educational resources implies a full understanding of the meaning of the intended scientific concepts. For this reason, we contend that professionals in the field of science education should not take it for granted that students will benefit from any educational simulation without analysing what students do and do not understand when they observe these simulations. This idea is in line with previous studies pointing out that the effectiveness of simulations varies with the particular students and contexts studied, and that simulations may have a negative impact on conceptual change for students with low prior conceptual knowledge (Dega et al., 2013). Furthermore, these results are also in agreement with those authors who state that in order to achieve effective comprehension of depicted scientific content, students need to overcome various difficulties (Ametller & Pintó, 2002; Colin, Chauvet, & Viennot, 2002; Stylianidou & Ogborn, 2002).

In addition, the wide variety of identified alternative explanations that can arise leads us to conclude that these explanations do not point in a single direction, but in fact depend on many different factors. In this sense, it is important to distinguish between content-dependent analysis of students' answers and content-independent analysis. From the point of view of the concepts underlying simulations, the identified alternative student explanations are closely related to other students' alternative conceptions from these or other educational levels. It is important to mention that students' alternative explanations do not only involve complex concepts, but also simple ideas that might seem obvious to teachers and designers. In addition, other commonalities in students' reasoning have also been identified, such as the substitution of the information depicted in the simulation by previous/accessible knowledge, or by simplified explanations wherein information has been eliminated or re-organized. Since very similar reasoning mechanisms were identified concerning student explanations vis-à-vis these two different simulations, we foresee that such reasoning could also appear in explanations concerning simulations of other specific scientific concepts.

On the basis of the above, we assume that the critical reading of images could play a central role in schools when students are using and visualizing scientific simulations. In order to receive the actual benefits which might be offered by simulations, teachers and instructional materials should scaffold students' reading processes and clarify students' explanations of the depicted content, thereby leading to more accurate understanding.

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Víctor López
Centre for Research in Science and Mathematics Education (CRECIM)
Autonomous University of Barcelona (UAB)
Spain

Roser Pintó
Centre for Research in Science and Mathematics Education (CRECIM)
Autonomous University of Barcelona (UAB)
Spain

MILTON SCHIVANI AND MAURÍCIO PIETROCOLA

7. PRAXEOLOGY AND THE USE OF EDUCATIONAL ROBOTICS IN THE TEACHING OF PHYSICS

INTRODUCTION

Nowadays, especially in large urban areas, life without the presence of a wide variety of "technological artefacts", such as traffic control, communication and information systems, smartphones, and food packaging, among others, is almost unthinkable. In addition, one cannot forget that most students in contemporary society (from the elementary to the university level) are already used to the dynamic and succinct modes of audio-visual communication and information common to TV, cinema, and, in particular, computers.

In addition to significantly influencing ways of life and means of production in society in general, the different forms and multiple expressions of the technologies that surround us have the potential to generate new teaching and learning situations. As Papert (2008, p. 14) points out, correctly, digital technologies and their multiple expressions offer unprecedented opportunities to promote quality in learning environments, "understood as being the entire set of conditions that contribute to shape learning at work, in school and leisure". In addition to the personal computer, digital technologies might be related to differentiated materials, such as those found in educational robotics (ER), which incorporates several options of plastic, metal or wooden parts, with different sizes and connections among them, with similar options for software, processing modules and sensors.

Since it is intrinsically playful and since it involves, either directly or indirectly, skills related to doing science, the field of robotics has become a strong contender as an educational instrument in recent years. Various research indicates that – through certain resources such as sensors, drives, programmable bricks, and graphic interfaces – it is possible to use ER to develop skills for solving logic and mathematical problems, to foster creative processes, to enrich critical reasoning, and to promote scientific literacy (Schivani, 2014; Benitti, 2012; Church et al., 2010; Mitnik et al., 2009; Lowe et al., 2008).

However, taking for granted the new and emergent resources that new technologies offer, as is the case with ER, does not necessarily imply that a given class will be better. As the Brazilian Ministry of Education acknowledges (Brasil, 2000), one of the main problems with the use of technologies in an educational capacity has to do with the forms of their use, rather than with the ends of their creation. The mere presence in the classroom of digital resources related to differentiated materials does not mean that the teaching and learning process will be automatically improved. An explicit didactic-pedagogical evaluation of the

M. Pietrocola & I. Gurgel (Eds.), Crossing the Border of the Traditional Science Curriculum, 115–125.

adequacy of the materials is necessary, especially when the goal is to teach scientific concepts.

Therefore, there emerges both the need for and the challenge to schools to function as critical spaces regarding the use and appropriation of such resources. One must be careful that the initiatives bringing computer or robotics kits to schools avoid these tools being restricted to use in "computer labs", without any direct integration with disciplinary knowledge.

The introduction of these technologies in teaching, specifically in the teaching of natural science, leads to a change in the roles of all who intervene in the teaching process. This shift occurs mainly in the role of the teacher, who takes on a more mediating role in an environment built to challenge and encourage the student to explore, reflect, and discover, and, in that of the student, moving him or her towards improved critical sense, increased capacities for analysis and synthesis, and a greater level of autonomy (Martinho & Pombo, 2009).

Two aspects must be taken into account here regarding technology in the school environment. The first has to do with the critical training of students, which entails making them aware of possibilities for responsible consumption of the objects that come from the new technologies present in society in general. The other has to do with the use of some of those objects (including digital technologies) as didactic-pedagogical resources, in order to foster the teaching and learning process. Therefore, we ask how digital resources can be used during learning to encourage the student to go beyond ready-made answers and to actually be the author and producer of his or her own knowledge. How can new technologies be used to help us both to teach and to learn scientific concepts?

When one explores the actual use of robotics as an educational instrument used to teach physics, it is necessary to create activities that will on some level relate the physics knowledge to be taught to the elements intrinsic to such technology. In other words, there must be a relation between the physics theory and concepts addressed (the "why") and the practice ("what is done"). However, how can one determine if such a connection is actually being made? How can one analyze the connections between the intrinsic features of robotics and the scientific content present in an innovation proposal? How can one ensure that there exists a resonance between those two different knowledge sets in order to optimize their use in the process of teaching and learning science, here, in the teaching of physics?

In order to answer at least some of these questions, we rely on the idea of Praxeology, the structural aspect of the Anthropological Theory of Didactics (ATD), as proposed by the French mathematician Yves Chevallard (1999). This theoretical instrument is used in order to understand human actions and activities in general, both shaping and organizing knowledge in terms of type of task, technique, technology, and theory. Since it proposes to deal with absolutely any sphere of human activity, ATD finds in physics, as a field of knowledge, a fertile domain in which to search for tasks and theoretical knowledge bodies that support its execution, even though the number of works in this area is still limited (Bosch et al, 2011).

THE IDEA OF PRAXEOLOGY

The origin of the term Praxeology is the union of two Greek words, *praxis*, which has to do with the practice of a certain task, and *logos*, which indicates the study of something. In the context of ATD, a Praxeology is expressed by the set [T, τ, θ, Θ], where T represents the type of task, which can ramify into countless tasks [t], τ represents the technique, θ the technology, and Θ has to do with the theory (Chevallard, 1999). Such structure allows to investigate the practice of a certain task correlating it with a logos, that is, with a conceptual-theoretical component. Mortensen (2010), for example, uses the structural aspect of ATD to investigate the experience and understanding of visitors to an immersion exhibition in a science museum; he seeks to verify both divergences and convergences between the praxeology expected in the exhibition and the praxeology observed in its visitors. In turn, Nogueira (2008) analyzes the introduction of algebra in elementary school textbooks using praxeological organizations as theoretical and methodological references. Along the same line of textbook investigation, Zanardi (2013) analyses, from the point of view of tasks, techniques, technologies, and theories, how contents related to the Clapeyron equation are addressed in both high school physics and chemistry books.

The idea of praxeology also allows us to shape and organize knowledge according to what Chevallard (1999) called Praxeological Organization (PO), which is made up of two different though correlated blocks: the practical-technical block [T, τ], which corresponds to knowing how to do things, and the technological-theoretical block [θ, Θ], which has to do with knowledge, that is, with the logical discourse that allows to us understand and better justify the practical-technical block. Since it may encompass any type of activity in which one can establish tasks to be executed and the knowledge that is in the base of their execution, a Praxeological Organization may be of different types: didactic, physical, mathematical, chemical, artisanal, industrial, rural, or domestic, among others. A didactic Praxeological Organization (didactic PO) is understood, a priori, as the set of the types of tasks, techniques, technologies, etc., that is mobilized for the specific study of a certain "work", in a proper "institution".

The Practical-Technical Block (Praxis)

From the start, the execution of a task, or type of task takes for granted the adoption of a certain technique. Therefore, people understand this pair as a practical-technical block [T, τ]. According to Chevallard, everything that a person is requested to do, anything mediated by verbs, may be called a task. In this sense, the word task evokes an action, a way to do something. It is a ramification of a broader network that the author calls type of task [T].

Activities developed within the scope of educational robotics – though they are in one sense dealing with a single phenomenon or physical concept – may request a broad set of "things to do", from the assembly of the "robots" to their programming, the calculation of the physical sizes at stake, the adequate use of sensors and processing modules, and so on. Therefore, we might have a type of task, T, "calculation of the vehicle's velocity", which includes a task "t", or calculation of the vehicle's velocity in Linear Motion (LM), using data collected by such and such sensor …, all that within the genre of "calculation".

In turn, the technique [τ] has to do directly with how to carry out a certain task that belongs to T. In that sense, it can be said that the technique is a sort of "knowing how to do" which only makes sense when it is tied to a task to which it is related. In order to establish a robot vehicle's velocity, for example, one can use different techniques, from using accelerometers attached to the vehicle itself to external mechanisms, such as the use of ultrasound and motion detection sensors. Each technique used to carry out this type of task (calculation of velocity) requires specific programming which must be suited to the system of hardware and software used, and which in turn suggests other tasks and techniques.

The Technological-Theoretical Block (Logos)

According to ATD, the discourse that interprets and justifies technique is understood as a technology [θ] (the term technology has a specific sense in this theory, very different from that commonly used). In ATD, technology seeks to explain and to clarify technique, to justify its use/efficiency, to ensure its success, and to favor, as far as possible, the emergence of new techniques.

The concept, in physics, of torque (τ) provides an example of this understanding of technology. The concept of torque allows us to better understand and justify the adoption of certain techniques, as when someone uses a pipe to increase the extension of a tire iron handle in order to make it easier to remove screws. Such a technique increases the lever arm (r, distance between the rotation axle and the point of application of force), which is directly proportional to the torque. Therefore, the torque resulting from the constant force (F) applied at a certain point of the pipe to turn the screw will be smaller according to the distance between that point and the rotation axle (depending on the angle between those two sizes), determined by the vectorial expression

$$\boldsymbol{\tau}=\boldsymbol{r}\times\boldsymbol{F} \tag{1}$$

According to Chevallard (1999), in an Institution [I], regardless of the types of tasks and related tasks, a type of task always brings with it at least a trace of technology [θ]. Technological elements are often integrated into the technique.

Theory [Θ] encompasses a second level of activity validation, in other words, it both explains and justifies the technology that includes the adoption of a technique, with solidity and persistence, to carry out a certain task. The theory resumes, in relation to technology, the role that the latter plays in relation to the technique. Therefore, technology and theory make up the technological-theoretical block [θ, Θ], which is strictly tied to "knowledge".

In general, one could also think about other justification levels, in a progression that tends toward the infinite, that is, theories to explain theories which, in turn, support other theories, and so on. However, according to Chevallard (1999, p.13), "the description presented here in three levels (technique/technology/theory) is often enough to cope with the activity that one wants to analyze". In addition, the justification of a certain technology is treated, in many institutions, through mere transmission to another institution, either real or supposed, considered as being the owner of the logical discourse that permeates that justification. That is identified in the classical examples of declarations and situations such as: "We show in mathematics …", "The Physics teacher announced …", "It has been seen in geometry that …" (Chevallard, 1999).

As far as the ER activities in the teaching of physics are concerned, the presence of the technological-theoretical block, that is, of a discourse that enables explanation of technique, expounding on why is it effective or why it works, becomes very important to us. Since we are not interested only in the execution of the task itself, but rather are concerned that students be able to explain and discuss the process they are carrying out in terms of theory and physics concepts, the idea of Praxeological Organization is useful for clarifying and interconnecting these factors, connecting praxis with logos (Schivani, 2014).

One of the greatest didactic difficulties in carrying out innovative proposals using robotics has to do with the need to integrate the various knowledge sets necessary to their execution. One can only envision applications of robotics in the educational scenario within a certain set of rules or methods. In other words, a student may understand, on a mechanical level, the algorithms involved in the development of a certain assembly, and thus be ready to carry out the entire activity without taking into consideration the physical aspects (both conceptual and theoretical) involved in that task. A given student may also reinforce the limited use of techniques to fulfill certain tasks. In these cases, concerns arise about scientific knowledge in relation to what the student is doing. This becomes even more clear when one observes the solving of problems by trial and error, a common approach within the scope of educational robotics (Barak & Zadok, 2009). Depending on the problem that must be solved, students may focus their attention mostly on technique, on the practical part of the activity, without much concern for the conceptual understanding of the matter at hand. Only after a few unsuccessful attempts and mistakes do they realize that their initial intuition is not an adequate tool with which to solve the proposed tasks (Rouxinol et al., 2011).

EDUCATIONAL ROBOTICS FROM A PRAXEOLOGICAL PERSPECTIVE

Educational robotics offers several options for sensors, drives, and spare parts with their own fittings, in addition to providing forms of software that use intuitive and easy-to-use graphic interfaces. This format allows for the development of multiple physical structures and, as a consequence, for the execution of countless tasks and the application of many different techniques. Thus, it is possible to create countless structures/systems (automatized heaters, barcode readers, communication systems, vehicles, androids, "intelligent" homes, braking systems, seismographs, machinery, etc.), which potentialize the imitation of a variety of "real" situations that might occur in a student's daily life or in society in general. These become "realities" or social practices that one may take as reference and problematize.

However, the use of this kind of instruments to teach science in general, and physics specifically, must overcome the techniques adopted to carry out specific tasks. In order to reduce the risks of wasting the potential of ER as a teaching instrument, it is necessary to create activities that will, on a basic level, relate the knowledge to be taught to the elements intrinsic to that technology; that is, one must pay attention to knowing how to do the task, the praxis, without forgetting the logical discourse that permeates and helps us understand that know-how, the logos.

From a praxeological perspective, we contend that if the occurrence of the technological-theoretical block is not identified (at least part of it, such as technology, for example) in the didactic activity, the modelling of knowledge will be jeopardized, since the disciplinary knowledge necessary to understand and/or to better solve the proposed task cannot be mobilized. Modelling involves idealizations, approximations, and the selection of significant variables, aiming at representing the problem in a simplified manner, either through pictorial, graphic and/or experimental representations, or through mathematical expressions, allowing us to determine, for example, physical relations and necessary restrictions, even though they are not directly observed (Karan, 2012; Greca & Santos, 2005).

In general, ER may lead to learning in a range of disciplines and to the development of certain competences such as, for example, reading, the articulation and interpretation of symbols and codes in different languages, and using representations (sentences, equations, schemes, diagrams, tables, charts, and geometric representations) to solve problems. It also allows the student to recognize the relations between different dimensions, or those of cause and effect, so that s/he can make predictions and decisions, either alone or in a collaborative manner (Church et al., 2010; Mitnik et al., 2009).

The assembly of a fork-lift (Figure 1) built with robotics kits and used for didactic purposes, may serve as a basis to show how the praxeological elements θ and Θ are present and how they correlate to tasks and techniques.

The main type of task [T] that may be carried out via that assembly has to do with the transportation (both horizontal and vertical) of loads, such as that of small objects (marbles, for example) of known mass. One of the techniques [τ] associated with the fulfillment and investigation of this type of task is to position the load, contained inside containers (made of paper and of different sizes), at a certain distance from the fork-lift's front wheels.

Depending on the distance between the center of gravity of the load and the central axle that goes through the front wheels of the fork-lift, there may be accidents, such as the load being dropped, or the fork-lift itself falling over. However, the understanding, both in theoretical and conceptual terms, of that connection (which is also a technique), and of the risk of accidents is only satisfactory to a minimum extent when one also understands the technology [θ], that is, when one comprehends the physical concept of torque by means of the lever principle.

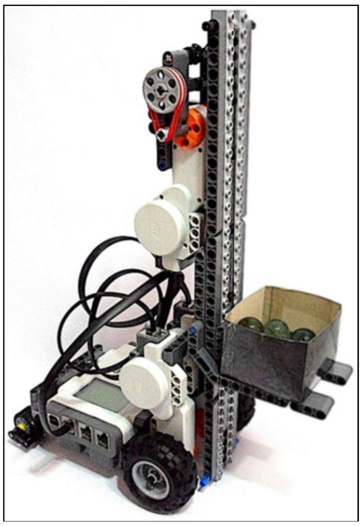

Figure 1. Fork-lift built with kits from Lego Mindstorms NXT

The central axle that completes the front wheels of the fork-lift make up the fulcrum (support point of a lever). In turn, the engines, the battery, and the processing module make up the counterweight. Even though it is a subtle connection, we can also identify the Θ (theory associated to technology θ) element in the law of conservation of energy, since, while the fork-lift's counterweight undertakes the work of applying a weight force on one of the extremities of the lever arm in charge of the power, the other extremity undertakes work on the load, keeping the fork-lift in stable balance. Therefore, this project embodies a complete didactic PO, with the potential to work both didactically and pedagogically with tasks and techniques that are justified and understood by a specific technological-theoretical block.

The great potential of educational robotics also comes to the fore when one thinks about the contextualized teaching of physics (Ricardo, 2010), since its mechanisms enable us to explore extensive physical dimensions (velocity, acceleration, time, force, torque, position, magnetic field, temperature, etc.), as well as the most diverse phenomena (sound, ultrasound, light intensity, heat transference, harmonic motion, capacitance, circular and straight motion, etc.). Therefore, one can observe that the idea of praxeology is a strong ally in the initiative to reveal and clarify, in terms of tasks, techniques, technologies and theory, the structure and dynamics between a given reality and its didactic activity (didactic PO).

If we start from a specific human activity, as included within a certain (research, industrial, commercial, and/or domestic) reality, we may investigate that activity by initially treating it as a Praxeological Organization (reference PO). Thereafter, depending on the didactic intention, one can extract from that initial reference PO investigation which tasks, techniques, technologies, or theories one wants to deal with or which are more useful for inclusion in didactic activity. This latter strategy is developed by means of what we call Praxeological Verisimilitude (PV) (Schivani & Pietrocola, 2013; Schivani, 2014).

PRAXEOLOGICAL VERISIMILITUDE AND EDUCATIONAL ROBOTICS IN TEACHING PHYSICS

Praxeological Verisimilitude (PV) seeks, basically, either to investigate or to develop didactic activities by taking into account certain tasks, techniques, technologies, and/or theories that are (either partially or entirely) similar between the didactic and the reference POs. Therefore, Praxeological Verisimilitude refers to (all or some of) the praxeological elements that are, to some extent, similar between two different praxeological organizations.

Within the scope of using educational robotics to teach physics, we can use a drawbridge, such as those found in various contemporary cities, as an example of the application of that concept (PV).

In the didactic PO, for example, one can use a robotics kit to build a reduced-scale drawbridge that can be operated manually by a winch. In this case, one of the techniques that one can use in the didactic PO – one also commonly used in the reference PO when carrying out the task of “raising the bridge” – has to do with the use of a reduction box, which uses gears to reduce rotation speed and to increase the available torque in order to help in the raising of the bridge (the main task).

In our specific assembly, the reduction box built in the bridge of the didactic PO is not the same (in terms of structure, location, and activation) as that used in the current drawbridges of the reference PO, since it is activated by hand by means of a winch. It may be built with metal shafts or in pieces made up of perforated plastic and is of a smaller size, as properly designed to fulfill the needs of the didactic PO. Therefore, although the physical structures present both in the didactic and in the reference PO refer to a drawbridge, the bridge developed in the didactic PO is not able to carry out the exact same task as that of the reference PO. This results in what we call a Correspondence Praxeological Verisimilitude (Correspondence PV) as far as the technique [τ] is concerned, since the mechanisms and procedures used in both POs (such as the reduction box) are similar but not identical.

On the other hand, the physical principle of how the reduction box in a drawbridge works, whether that of a given drawbridge in a given city or that of the didactic activity, is exactly the same for both cases, regardless of the magnitude of the type of task carried out. We refer to this connection regarding technology and theory as Praxeological Verisimilitude by Intersection (PV by Intersection), since one can understand how the mechanism works, both in the reference and in the didactic PO, by means of the same technological-theoretical block [θ, Θ]. For example, in this instance, one may apprehend the workings of either drawbridge by means of the relations of gear transmission and of vectorial decomposition (or force and torque).

Another example which may be used to illustrate the notion of Praxeological Verisimilitude has to do with electronic speed monitors. This type of speed monitor operates via the agitation of the electromagnetic field, as generated by coils installed in the street under the asphalt. Two coils (of the magnetic lace type) are placed on the street at a predetermined distance from one another. Such coils are installed around 20 meters before the tower (that shows the speed) and ordered in the same way as the traffic flow. When the recorded speed is greater than the speed limit, a photographic camera is activated. One of the techniques used to determine the vehicle's speed involves simple kinematic calculations.

By means of educational robotics, one can "replicate" such a system and explore that reference practice in the classroom, by building both the electronic speed monitor system and the vehicles (in small scale) using different kits and materials. However, it is necessary to be sure about which tasks, techniques, technologies, and/or theories of the reference PO one wishes to explore, and whether those praxeological elements will appear in the didactic PO through an intersection PV, a correspondence PV, or both.

Upon first analysis, the type of task (determining the speed of vehicles that go by a stretch of road) and the main technique associated with that type of task (placing detectors on the road so that the time elapsed between two peaks of the signs detected are processed by the tower to calculate the speed) are an intersection PV. Thus, the didactic PO may have exactly the same type of task and the same technique contained in the reference PO, which increases the amount of praxeological elements that may be discussed in the disciplinary knowledge modelling process. Thus, it is possible to address physical concepts such as average speed, instant speed, average acceleration, and instant acceleration, in addition to the techniques used for recording and measuring the time elapsed between the signs activated when vehicles pass.

By using robotics components, one can develop different fabrications that are permeated by the multiple techniques necessary for carrying out the main type of task (here, determining a vehicle's speed). One can use many types of sensors, from ultrasound and infrared to light sensors, as well as those of different materials and assemblies; students are compelled to investigate the best option, both in terms of efficiency in measurement and complexity of assembly. Students' creativity is explicitly valued in this process, and the use of their logical reasoning to solve problems gains major importance vis-à-vis both physical and mathematical concepts. This involves a correspondence PV, since students will obviously not use the exact same equipment, structures, and materials present in the reference PO.

Finally, taking into account the wide variety of materials offered by educational robotics, it is possible to change certain techniques to approach the particular reality one wants to explore. Therefore, if there is interest in exploring similar techniques in the didactic PO, similar, that is, to those that use variations of the magnetic field to record the passage of a body between one point and the other (as occurs with the electronic speed monitor), one could use a Hall effect sensor, which works as a transductor that varies its exit tension in response to an external magnetic field. This iteration might further increase students' freedom and involvement, allowing them the creativity to explore a variety of proposed problems from different angles, and to engage with the world them with new perspectives and increased possibilities for both action and understanding.

FINAL THOUGHTS

The resources offered by new technologies are increasingly present within the educational scenario. Therefore, it is both necessary and pertinent to debate possible analytical strategies and explore the development of didactic activities that effectively use those resources.

Educational robotics, when used for teaching physics, allows a broad approach that may include several objects of a given PO. However, we warn that this alone is not enough. With the goal of encouraging students to think about and to interconnect both theory and practice, the resources that educational robotics offer may be used during the teaching and learning process by taking the two blocks – the practical-technical and the technological-theoretical – into consideration. These blocks must be strongly and successfully interconnected in the didactic activity. In order to avoid empty and "alienated" activities one must pay attention to know-how, or praxis, without forgetting the logical discourse that permeates and helps in the understanding of that know-how, the logos.

In that aspect, we note that ATD, mainly as far as its structural component (praxeology) is concerned, presents itself as an effective theoretical tool for understanding both the limits and the possibilities of robotics in situations that involve tasks that require specific physics knowledge. We find ATD especially useful in highlighting the praxeological elements that are actually developed in the didactic PO, with echoes in the natural phenomena and/or human activity that one wants to contextualize.

If the technological-theoretical block, or at least part of it (a technology, for example), is not identified within the didactic PO, the modelling of knowledge so important to the teaching of physics is seriously damaged. If the didactic PO does not include even a fraction of the technological-theoretical block in order to better understand the techniques used in the fulfillment of certain tasks, the mobilization of disciplinary knowledge runs the risk of being incomplete or even non-existent.

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Milton Schivani
Department of Theorical and Experimental Physics (DFTE)
Federal University of Rio Grande do Norte (UFRN)
Natal-RN, Brazil

Maurício Pietrocola
Department of Teaching Methodology and Comparative Education
School of Education of the University of São Paulo
São Paulo-SP, Brazil

CIBELLE CELESTINO SILVA AND
PEDRO DONIZETE COLOMBO JR.

8. TEACHING SOLAR PHYSICS IN A PARTNERSHIP BETWEEN FORMAL AND NON-FORMAL EDUCATION

INTRODUCTION

This chapter presents an innovative approach to teaching modern physics in high schools based on a partnership between physics teachers and a science center team in the teaching of solar physics contents. The science center concerned is the Dietrich Schiel Observatory of the University of São Paulo. This center's Solar Room, a space equipped for and devoted to the dissemination of solar physics topics, was also utilized.

The use of science centers for learning is a rising phenomenon, which may well be intimately related to the increasing impacts of science and technology on society. In different parts of the world, cultural institutions that are rich in terms of science (such as science centers) have collaborated with schools by supplying students, teachers, and families with opportunities to expand both their experiences and their understanding of science (Bhatia, 2009; Bevan et al., 2010; Salmi, 2012).

By addressing solar physics and discussing the partnership between a science center and high schools, this chapter seeks to contribute to the possibilities for developing methods of teaching physics that are closer to students' experience and to provide a discussion about "learning to teach in innovative ways". As far as "learning to teach" is concerned, we seek to offer teachers new methodological approaches and new reflections on the practice of teaching, including ways of rethinking that practice, the evaluation of activities, and the process of retro-feeding activities discussed with the students. At the same time, this "innovative way" reflects a partnership between formal and non-formal education, strategy, and new contents (solar and modern physics).

In the current study, learning to teach in an innovative way comes into effect in Teaching-Learning Sequences (TLS) developed in partnership with teachers and mediated by what we call reflective cycles, which we developed in our partnership between formal (school) and non-formal (science center) education. The development of TLSs relied on a broader approach known as Design-Based Research [DBR] (2003). According to Juuti and Lavonen (2006), DBR features three characteristics: "a) a design process is essentially iterative; b) the objective of a design-based research is to develop an artefact to help teachers and pupils to act (teach and study) more intelligibly (in a way that leads to learning); c) design-

M. Pietrocola & I. Gurgel (Eds.), Crossing the Border of the Traditional Science Curriculum, 127–141.

based research renders novel knowledge about science teaching and learning" (Juuti & Lavonen, 2006, p. 59).

Our study involved an elaboration of TLS (Lijnse, 1994, 1995; Méheut, 2004; Méheut & Psillos, 2004; Komorek & Duit, 2004; Lijnse & Klaassen, 2004; Viiri & Savinainen, 2008) that encompassed activities both in the classroom and in the Dietrich Schiel Observatory of the University of São Paulo. One can understand TLSs as a set of lessons about a specific theme (which is not necessarily related to the school curriculum) that lasts for a few weeks. The sequences evolve progressively, with two main characteristics being inclusion within a gradual teaching process and the intertwining of the teaching of science with the student's perspective. TLSs may be used as a tool both for research and for curricular innovations, since they enable the production of contents that are different from those found in the textbooks, in the sense that they seek to include both scientific knowledge and knowledge to be taught.

We used a methodology that we called "reflective cycles" to guide our research. Reflective cycles may be interpreted as ongoing partnership actions between teachers and researchers, starting with teacher preparation, continuing through the elaboration of activities, and culminating in TLS implementation with students.

The goal of this text is to present and discuss this collaborative methodology, as used in the construction and implementation of the sequences. In this discussion, the close proximity between formal and non-formal education modes emerges as key for the teaching-learning process, as do the roles of the teachers in the approach, as mediated by the reflective cycles, and those innovative aspects brought by TLS to modern physics for students.

SOLAR PHYSICS AND THE DIETRICH SCHIEL OBSERVATORY

What is the Sun? What is it made of? How does it produce its energy? Why is it important to study the Sun? These are common questions posed by people visiting astronomical observatories and planetariums. Despite its interest, relevance, and didactic potential, solar physics is seldom taught in high schools or even in teacher training courses. We chose this theme because it enables an interdisciplinary approach to modern physics topics, such as spectroscopy, atomic models, and astrophysics.

In order to realize the educational potential of solar physics, the Dietrich Schiel Observatory built a Solar Room[1] which is open to the public, universities, and schools. The Solar Room is equipped and devoted to the study of the Sun and to the dissemination of science. Approximately $10m^2$ in area, the space is paneled with pictures of several solar structures and star spectra, and contains a spectroscope built to study the solar spectrum, a 200/2000 Newtonian telescope with a 42mm ocular which projects the sun on a screen, and a computer used to observe solar activities in real time, by means of access to specialized websites. There is a heliostat on the outside roof of the Solar Room which has electronic controls for the position of the Sun's image throughout its daily movement, and is connected to a telescope that projects an image of the Sun in a 1.2 m x 1.2 m white screen inside the room (Figure 1), enabling the observation of sunspots and solar faculae (Hönel, 2004).

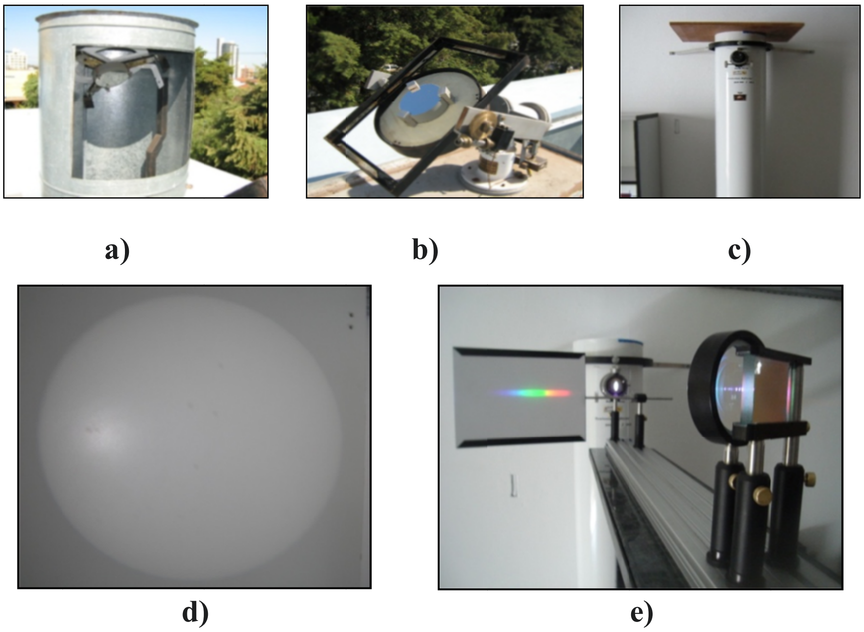

Figure 1. Heliostat Operation Stages: a) the fixed mirror, b) the mobile mirror, and, c) the tube of the telescope located inside the Solar Room; d) illustrates the projection of the Sun's image on a screen inside the Solar Room, and e) illustrates the use of a spectroscope to observe solar spectrum absorption. (Source: Dietrich Schiel Observatory, http://www.cdcc.usp.br/cda/interno/heliostato/index.html)

In the Solar Room, the observation of phenomena that take place on the solar surface, such as sunspots and faculae, allows teachers to start discussions about the very nature of the Sun as a dynamic star, and to work with students on science contents such as electromagnetism and thermodynamics. Other discussions that might take place include those about the origin of chemical elements (via exploring concepts regarding stellar evolution), the transportation of energy produced by the Sun, the flares – gigantic explosions in the surface of the Sun – which eject radiation as charged particles, gas, electrons, visible, ultraviolet and X-Ray light in the interplanetary medium, as well as geomagnetic storms (Bhatnager & Livingston, 2005). In this research, such actions were incorporated in the collective construction of TLSs by means of reflective cycles and they provide a new path for work with modern physics in schools in Brazil and elsewhere.

REFLECTIVE CYCLES AS A COLLABORATIVE METHODOLOGY FOR THE DEVELOPMENT OF TEACHING-LEARNING SEQUENCES

TLSs and Their Phases

The reflective cycle is a research and development method we created for our formal/non-formal partnership. This methodology includes three interconnected phases: Phase A: constitution of the work group; Phase B: teacher training, with collaboration between researcher and teacher; and, Phase C: application, ongoing evaluation, and re-elaboration of TLSs, in a system of reflective subcycles that includes both the formal and non-formal education environments and their agents, that is, researchers and teachers.

The idea of reflective cycles was inspired by the participative action research of Eilks et al. (2004), which considers curricular innovations as best explored and developed in circles of retrospective understanding and future action. Eilks et al. (2004) focus their ideas on research into the History and Philosophy of Science (HPS), as reflected in their "Model of HIPST" (Model of History and Philosophy in Science Teaching). In this model, the teaching of ideas, concepts, and strategies is planned, evaluated, and reworked in cycles. The researchers state that strong teacher participation is typical. A key focus is the sharing of ideas and perspectives according to the different skills and knowledge of those involved. The teachers are in charge of structuring the developmental processes and of defining the central issues to be addressed in regular meetings (Höttecke et al., 2012, pp. 1251–1252). Inspired by the HPS work of Eilks et al. (2004), Henke et al. (2009) and Höttecke et al. (2012), we developed the idea of reflective cycles that focus on partnership between formal and non-formal education and on the process of curricular innovation.

Taking our main goals into account, reflective cycles may be interpreted, along with their phases of development, according to Figure 2.

Understood as a methodological tool, reflective cycles are used to research ways in which we may learn to teach innovatively, based on the joint elaboration of teachers and researchers (observatory staff) of the Teaching-Learning Sequence. The following tables (Tables 1 to 4) comprise our systematization of the reflective cycles as experienced in the context of our project, giving special attention to learning to teach in an innovative way and to the materialization of that type of learning in our TLS.

Up to this point, the reflective cycles encompass possibilities for thinking about ways of learning to teach, based on the work of teaching preparation and on the study of topics of solar physics with the teachers. However, the materialization of ideas that embody innovative teaching and learning was sought in the second part of phase B, in the search to encourage the initial construction of the TLS. During this period, the partnership between teacher and researcher became more intensive. The teacher's experience took on the leading role in the reflective cycles, given that the teacher is the agent most able to point to the specific aspects of her or his school, its sociocultural environment, didactic time, adequacy as regards previous knowledge, and possibilities for work with particular groups of students.

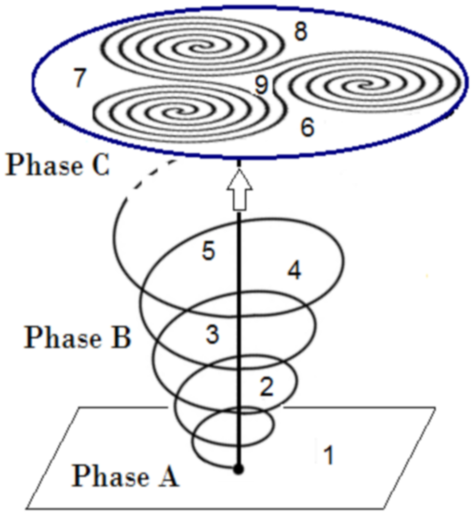

Figure 2. Representation of reflection cycles. Phase A: 1. Constitution of the working group; Phase B: 2. Contents update, 3. Sharing of ideas and perspectives, identification of problems and possible solutions, 4. Gathering of already-available materials, 5. Initial development of the TLS; Phase C: 6. Application of the material developed, 7. Ongoing evaluation and re-elaboration of the TLS, 8. Availability of the material and the TLS, 9. Sharing of ideas and perspectives, identification of problems and possible solutions – feedback (Colombo Jr. et al., 2013; Colombo Jr., 2014)

Table 1. Phase A

Constitution of the Working Group	
Theoretical aspect	Initial moment when the rules for the constitution of the working group that will monitor the research in its different stages are defined. The selection of participants should take into account, among other things, the goals of the research, the dynamics of the work, the academic training of the participants, and their level of availability for the preparation and execution of research proposals.
Contextualization in Research	We invited teachers who taught in Brazilian public high schools and who wanted to voluntarily participate in this research to make up our working group. The selection requirements were: being a tenured teacher, being trained either in physics or chemistry, being able to volunteer, and being available to participate in training meetings on Saturdays at the Dietrich Schiel Observatory. Seven teachers were selected, with four of them attending the full course and two being placed in charge of applying the elaborated TLS.

Table 2. Phase B

Contents Update	
Theoretical aspect	Although it is within one of the phases of the reflective cycles, this stage involves the overall development of the research, both in the classroom and in the science center to be visited. The goal of this stage is to provide research participants with moments of both theoretical and practical learning around the themes that will be discussed with the students. Understood as part of ongoing training, actions and activities should be proposed that the teachers may use in convenient moments during the research, such as in the elaboration of the TLSs and while working with students.
Contextualization in the Research	The teachers' preparation consisted of eight meetings, for a total attendance of approximately 40 hours of activities. Most of the meetings took place on Saturdays at the Dietrich Schiel Observatory. One week before the meetings, teachers received a synthesis, in the form of a descriptive text, of the topics that would be discussed. This measure enabled teachers to have some notion, albeit potentially on a superficial level, of the topics that would be addressed.

Sharing of Ideas and Perspectives, Identification of Problems and Possible Solutions.	
Theoretical aspect	The sharing of ideas and discussions about specific content, as well as its related didactic and pedagogical issues, is intrinsically related to the previous item. The act of sharing ideas and identifying problems invites the teacher to (re)think his or her teaching practice and to bring into the social discussion both the difficulties and the perspectives that s/he has regarding the project to be developed. This approach acquires new meanings when the teacher evaluates and reconstructs her or his lesson aiming at the application of the TLS.
Contextualization in the Research	In our research, the teachers were invited to keep a written record of their perspectives regarding the project and, later, to indicate the possible problems they believed could appear in the development of such work. In meetings with peers and researchers, the teachers were encouraged to read their records and to share their conflicts and issues, along with any possible guidance toward solutions. Such actions greatly enriched the project, since the sociocultural contexts in which teachers were immersed were brought to the fore, and each revealed aspects of their didactical and pedagogical experience.

Gathering of Already Available Materials	
Theoretical aspect	Understood as a selective stage of the reflective cycle, this is when both teachers and researchers re-visit the texts and notes created during teaching preparation, and when they search other sources for both materials and activities that may be a part of the TLS to be developed in the following stage.

Contextualization in the Research	The teachers were encouraged to look for references to the Sun in the physics and chemistry textbooks used in their schools, whether in the scope of solar physics or in that of chemistry, for example, in nuclear fusion, radiation, etc. Materials were also sought through the Internet, enabling the use of solar physics as a means to approach certain topics of modern physics with the students, such as: the use of Applets, simulators, experiments, demonstrations, videos, films, and texts, among others. This research encouraged the execution of works in the following stage, the initial building of the TLS.

The building of TLS relies on the Design-Based Research (DBR) methodological approach (Juuti & Lavonen, 2006). This approach is an important methodology for understanding how, when, and why educational innovations work in practice (DBR, 2003):

> […] design-based research methods can compose a coherent methodology that bridges theoretical research and teaching practice. Viewing both the design of an intervention and its specific enactments as objects of research can produce robust explanations of innovative practice and provide principles that can be localized for others to apply to new settings. Design-based research, by grounding itself in the needs, constraints, and interactions of local practice, can provide a lens for understanding how theoretical claims about teaching and learning can be transformed into effective learning in educational settings. (DBR, 2003, p. 8)

DBR focuses on a perspective in which the use of different methods enables researchers to analyze the results of an intervention in the educational context. Therefore, an innovative proposal becomes a product of the planned intervention and of the intervention context itself (Pietrocola, 2010). This research is grounded in the DBR-TLS perspective and its implications go well beyond the elaboration of a specific, complete, private product. On the contrary, it seeks innovation in real learning environments and with the participation of teachers as the protagonists of the process.

The TLS and its Design

The proposal of enacting a teacher-researcher partnership (between formal and non-formal modes of education) using the reflective cycles supports the ongoing work of debating and of (re)thinking teaching practice. To that end, one of our first steps was the preparation of teachers for partnership work. Table 5 shows a synthesis of the efforts that were carried out during the first teaching preparation meetings. We agree with Pietrocola (2010) that opting for DBR, in combination with the TLS approach, is an efficient means of constructing safe pathways for overcoming the risks inherent to the processes of curricular innovation (in terms of

Table 3. Phase B (continued)

Initial Development of the Teaching-Learning Sequences (TLSs)	
Theoretical aspect	This is a rich moment in the partnership between formal (school) and non-formal (science center) education. It is the moment when the teacher, as representative of the school environment, makes explicit both his or her desires and his or her choices of themes deemed important to the TLSs. On the other hand, the researcher dialogues, proposes, and discusses his or her interests as well, seeking to adapt the TLSs to her or his desires for the partnership and research issues. It is important to emphasize that the development of a TLS begins, either directly or indirectly, at the moment when the working group is constituted. It can be understood as starting with the selection of contents, gathering of materials, and early socialization between teachers and researchers. A TLS is ultimately built through research data during its implementation with students, which justifies referring to this phase of the reflective cycle as "initial development".
Contextualization in the Research	Two TLSs were developed, taking into account the requests of applicant teachers in the schools. The elaboration of the TLS and of didactic materials (activities) for students took place based on the negotiation between teachers and researchers, and can be summarized as follows: (1) First, the researchers presented a summary of the subjects approached during the teaching preparation mini-courses. The goal was to recall what had been worked on during the months of teaching preparation. This moment also reflects the initial steps of the reflective cycles, in which the working team that has been established shares problems, solutions, and expectations for the elaboration and application of the TLS. The team discussed such aspects as didactic time, possibilities for developing activities in the schools, and student profiles. (2) Next, the teachers presented those aspects of the textbooks used in their schools that focus on modern physics issues. In presenting these materials, the teachers had the autonomy to adjust the TLSs according to the textbooks they were used to working with, although they were offered a new approach to working with their chosen subjects. (3) After that, a debate was held about how to work on the issues that the teachers chose (and others that are not discussed in the books) in order to enable the use of solar physics as a means for approaching modern physics topics. Thus, both teacher autonomy and in-place curricular proposals were respected, rendering the partnership more valuable. (4) After the choice of topics for the TLS, exercises, demonstrations, and experiments that could support the themes that would be worked on with the students were selected. As with the previous stage, the summary texts given to the teachers for the five teaching preparation meetings were also taken into consideration. Because of this, the TLS contained not only exercises, but diversified textual constructions, guidelines for experiments, and Applets as well.

Table 4. Phase C

Application of the Developed Material – Ongoing Evaluation and Re-Elaboration	
Theoretical aspect	In the application phase of a TLS, crucial attention must be paid at all times to the dynamics of its ongoing construction, that is, the TLS must be constructed (reorganized) at the moment of its application, by being constantly fed by research data. Thus, it is expected that a TLS may be applied in at least two classrooms, with a gap between the beginnings of the applications that allows its reorganization. This approach attends to the origin of TLSs, in which they derive from evolutionary cycles illuminated by research data (Lijnse, 1995) and to research along the DBR line (Eilks et al., 2004; Henke et al., 2009; Höttecke et al., 2012).
Contextualization in the Research	Seeking to fulfill the theoretical aspect of the application of the TLS, its inception in different classrooms took place, on purpose, with a delay of two weeks between the classrooms of the same school, and in different times between the schools that participated in the research. The goal of this decision was to allow space for discussion, evaluation, and reflection as the TLS were developed with students, and to allow the teachers to re-elaborate them for the second application. Discussions about the application of the TLS were nonstop during their application, with weekly meetings being held with the teachers, in their schools. Beginning the TLS in different moments both in the schools and in the classrooms, was a methodological strategy that allowed the teachers to review and adapt the TLS during the application process. We understand that this fact represents a significant gain for the procedural bias of teaching and learning activities, since it allows for the reviewing of decisions, changes in approaches, and inclusion of topics that were not evaluated in the initial application, besides making an ongoing dialogue between teachers and researchers possible. It also represents an important aspect of learning to teach in innovative ways, since the Teaching-Learning Sequence and its repercussions for the students involved become part of an ongoing interactive learning experience.

Availability of the Material and of the TLSs – Sharing of Ideas – Feedback	
Theoretical aspect	The last stage of the reflective cycles has to do with disclosure and with making all of the material produced available to serve teachers and students. The disclosure of the results of the research is a way to contribute to the success of other schools and teachers via access to the work, thereby giving back to society the balance of its investment.
Contextualization in the Research	The disclosure of the present research focuses on the publication of scientific articles, and on participation in national and international conferences and meetings in the field of the teaching of physics.

Table 5. The teaching preparation course

Meeting	Goals	Duration
I	– To deepen knowledge of the theoretical aspects of non-formal education, focusing on education in science centers and museums, and its relation to formal school learning sets. – To discuss concepts related to curricular innovation and Teaching-Learning Sequences with the teachers involved in the research. – To present and discuss the notion of the Didactic Transposition of scientific contents with the teachers involved in the research.	4 to 5 hours
II and III	– To substantiate and discuss (in a theoretical and practical/experimental manner) the modern physics topics (spectroscopy) related to the research. – To carry out experimental and low-cost activities using solar physics as a means to work on modern physics in high schools.	10 to 11 hours
IV and V	– To explore topics related to solar physics in both theoretical and practical manners. – To carry out practical activities involving observation of the Sun at the Dietrich Schiel Observatory of the University of São Paulo, Brazil.	10 to 11 hours
V	– To build, together with participating teachers, Teaching-Learning Sequences which contain both theoretical and practical activities, and which incorporate work done in the classroom (formal education) and in the Observatory (non-formal education). – To define, in accordance with participating teachers, a schedule for the application of the proposed Teaching-Learning Sequences.	13 to 14 hours
	Total (approximately)	40 hours

method or content – or both). Therefore, the TLS that we propose emerges amid negotiations between multiple demands of different natures: teacher, researcher, formal and non-formal contexts, school community.

As far as the joint elaboration of the TLSs was concerned, our process went beyond the simple systematization of themes, contents, and dates. On the contrary, Phases B and C of the reflective cycles took into account teaching experience, school context (both structural and pedagogical), standing curricular proposals, already-developed teacher contents, and the roles of the reflective cycles in their construction. Two TLSs were elaborated, which were different in terms of structure, themes, and approaches and – taking into consideration the sociocultural context of each school – also included roadmaps to activities and texts meant to enable students to benefit from the TLSs both in their classrooms and in the Observatory. In order to illustrate the work developed from the reflective cycles, we present, in Table 6 (Colombo Jr., 2014), a TLS which resulted from various versions that were discussed by the team, and was elaborated for work with students both in the classroom and at the Dietrich Schiel Observatory.

Table 6. Teaching-learning sequence

MOMENT I The Sun			
Learning Situation 01			
Theme		Didactic Resources and Readings	Lessons
The Sun and Solar Activity		• PowerPoint Presentation (Lecture) • YouTube videos about the Sun • Didactic Texts about solar physics • Experimental Activity / Exercises	03
General Goals		• To present the Sun and its structures • To understand nuclear fusion and the Sun as a power source • To calculate solar diameter	
Learning Situation 02			
Theme		Didactic Resources and Readings	Lessons
The Sun as a Black Body		• PowerPoint Presentation • Didactic texts about black body radiation • Experimental activity: "Estimating the luminosity and the temperature of the solar photosphere" (Caniato, 1990).	04
General Goals		• To debate the emergence of Quantum Mechanics and the quantization of energy • To seek to understand the concept of black body radiation • To calculate the power irradiated by the sun and the temperature of the solar photosphere	
			Total: 07

MOMENT II SPECTROSCOPY			
Learning Situation 03			
Theme		Didactic Resources and Readings	Lessons
Electromagnetism		• PowerPoint presentation • Texts on the electromagnetic spectrum and the Bohr atom • Fixation exercises	02
General Goals		• To understand the electromagnetic spectrum • To work on the Bohr atom and electronic transitions • To understand Kirchhoff's Laws for spectroscopy	
Learning Situation 04			
Theme		Didactic Resources and Readings	Lessons
Applications of Spectroscopy		• PowerPoint presentation • Theater staging by the students: "How do lamps work?" • Activity "Building an amateur spectroscope" (Azevedo, 2008; SEE/SP, 2009; NUPIC, 2011).	

<table>
<tr><td rowspan="5"></td><td>General Goals</td><td colspan="2">To build and to discuss an amateur spectroscope
To debate the spectra of different lamps used in daily life
To prepare the students to visit Dietrich Schiel Observatory</td><td>03</td></tr>
<tr><td colspan="4">Learning Situation 05</td></tr>
<tr><td colspan="2">Theme</td><td>Didactic Resources and Readings</td><td>Lessons</td></tr>
<tr><td colspan="2">Spectroscopy in the non-formal education environment</td><td>Introductory text: “A Guided Visit to the Dietrich Schiel Observatory”
Visit to the Observatory
Experimental activity: “The Solar Room and the Solar Spectrum”</td><td rowspan="2">Didactic Visit (> 02)</td></tr>
<tr><td>General Goals</td><td colspan="2">To visit the Observatory (spectroscopy in a non-formal environment)
To compare different kinds of lamp spectra and the solar spectrum</td></tr>
<tr><td colspan="4"></td><td>Total: > 7</td></tr>
</table>

<table>
<tr><td rowspan="4">MOMENT III – Systematization</td><td colspan="4">Learning Situation 06</td></tr>
<tr><td colspan="2">Theme</td><td>Didactic Resources and Readings</td><td>Lessons</td></tr>
<tr><td colspan="2">Feedback on previously-studied issues</td><td>Use of Applets – computer room
Final evaluation activity</td><td rowspan="2">04</td></tr>
<tr><td>General Goals</td><td colspan="2">To use resources from multiple media as a way to systematize what has been worked on during the lessons
To propose a final evaluation – one of the evaluation stages of the course</td></tr>
<tr><td colspan="4"></td><td>Total: 04</td></tr>
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FINAL COMMENTS

Curricular innovations can barely impact the practice of school science teaching without the adoption of measures for overcoming the obstacles preventing innovation from being widely implemented (Höttecke et al., 2012). In this project, the adaptation of contents to school schedules and the time necessary for carrying out activities, as well as the challenges of working with new physics themes, such as modern physics, were some of the obstacles faced in the process of elaboration of the TLS with participating teachers. Our formal/non-formal partnership and our situating the teacher as the protagonist-agent of innovation were key for the execution of the proposal with the students. The partnership with the teachers became crucial to a greater level integrity in our design and actions.

> […] it is important to understand intended user teachers’ competence, beliefs, intentions, and attitudes toward the topic concerned in the design; or, in other words, to share teachers’ worlds. (Juuti & Lavonen 2006, p. 61)

Our work with solar physics in a school-science center partnership opened new horizons for discussions about learning to teach in innovative ways, at times instrumentalizing the teacher and, in general, supplying new methodological approaches for the practice of teaching. The execution of TLSs based on ideas from DBR brings research closer to teaching and reveals new fields of possibilities for teachers working with both modern and solar physics.

Our reflective cycles, in turn, involved more than the simple collaborative methodology used in the construction and implementation of the sequences. They emerged from the outset as a necessary "tool" for realizing our formal/non-formal partnership. Based on ongoing teaching preparation and reflection about the practice and adaptation of the TLSs to the school niche, the reflection cycles not only addressed "learning to teach", but also "innovative ways" to do so, as seen in the tables presented throughout the chapter.

We hope this text enables readers to consider the possibilities for formal/non-formal educational partnerships and the importance of collaborative work substantiated in innovative ways, such as the reflective cycles utilized in this project. In future publications, we will seek to broaden this debate by presenting analyses of the implementations of the TLS with the students in the classroom and in non-formal educational spaces.

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NOTE

1 Inspired by the solar space of the "Planetarium Foundation of Rio de Janeiro" (Aroca, 2009).

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Cibelle Celestino Silva
Institute of Physics – São Carlos
University of São Paulo
São Paulo-SP, Brazil

Pedro Donizete Colombo Jr.
Department of Education in Science, Mathematics and Technology
Federal University of Triângulo Mineiro
Minas Gerais-MG, Brazil

IVANI T. LAWALL AND MAURÍCIO PIETROCOLA

9. CURRICULAR INNOVATION IN MODERN AND CONTEMPORARY PHYSICS IN ONGOING TRAINING COURSES

Professional Profile, Motivation Change, and Teacher Difficulties

INTRODUCTION

Social changes naturally generate the need for updates in schools. The introduction of new values and behaviors inevitably leads to a rethinking of the roles of schools in society's new and developing contexts. In particular, teachers may be asked to review their practices, with the goal of changing routine teaching methods and contents. When the Law of Directives and Bases of National Educational (LDB) was put into effect in 1996, we found ourselves in just such a situation, with new directions indicated for both secondary and professional education. This document clearly expressed the challenges that education was facing as a result of society's transformation by the means of production entailed by new technologies, as well as by the value of information in a world dominated by real-time communication.

Brazil's National Curriculum Parameters, published from 1998 on, were a consequence of that pressure for change, and had an impact on the manner of organization of the entire country's teaching systems, even though the amount of actual implementation in the classroom has been modest (Ricardo, 2005). In recent years, mainly in Europe and in the United States, projects such as Introduction to Science Teacher Training in an Information Society (STTIS), and Science 2000,[1] have sought to deal with a society being transformed by science and technology. According to Pietrocola (2010), when analyzing how science courses are taught, it is not difficult to notice that a logic of *school survival* prevails. Science teachers replicate processes legitimized in the past. In that sense, school disciplines are supposedly the result of didactic transposition, in which there is transformation, implementation, judgement, and, finally, stabilization of school knowledge vis-à-vis the formative goals and determining factors of the classroom. Both in science and mathematics teaching, the knowledge that is taught, as generally associated with teacher activities, results from didactic transpositions that have already acquired some stability. The proposal of changes faces a tacit consensus regarding questions like "Why teach?", "What to teach?", and "How to teach?", which result from several years/decades of accumulated experience both in the use and in the adaptation of teaching activities. The preferred environment for such sedimentations of experiences has been classrooms and didactic laboratories. Its players have included, among others, teachers, students, and parents. Its main

M. Pietrocola & I. Gurgel (Eds.), Crossing the Border of the Traditional Science Curriculum, 143–162.

screenplays have been textbooks, and its background the educational system to which they refer. Traditional teaching in a certain school discipline is framed as the result of stabilized school knowledge and, therefore, as resistant to any changes or innovation.

Since they are the main players in the didactic transposition process, the act of dealing with teachers in innovation situations is especially important. Pintó et al. (2005) claim that it is not enough for the teachers involved in a curricular innovation process to admit that a proposal is innovative in itself, but they themselves must both translate it and decode it according to their theoretical and practical background. The teachers must be able to recognize and acknowledge their own transformative role in the innovation process.

Shulman (1986) emphasizes that a very important aspect of the analysis of teaching – one which investigations on didactics have long ignored – is the extensive knowledge that teachers have of teaching contents and of how these contents reach the students. The author elucidates the various categories of teacher knowledge bases, which may be summarized as follows: knowledge of specific content (related to the specific content of the subject or subjects that the teacher teaches), general pedagogical knowledge (including knowledge about theories and principles related to teaching and learning processes), and pedagogical knowledge of the content (Pedagogical Content Knowledge). The latter is a new kind of knowledge that the teacher constantly builds when s/he teaches a subject, which allows him or her to expose ideas in the ways most effective for student learning. In this process, s/he seeks to utilize the most important and useful analogies, descriptions, examples, explanations, and demonstrations, seeking to render the subject comprehensible. The analysis of such knowledge is important, since the teacher does not acquire it in his or her training. This knowledge is a personal elaboration by the teacher, acquired during years of practice, through confrontation with the process of transforming content learned during training in teaching content. It is at this point that personal values, motivations, and obstacles are present in the teacher's practice, shaping those transformations in ways relevant to any analysis of teaching, as well as teaching practice writ large. Chevallard (1991) calls this process "Internal Didactic Transposition": the transformation of content in the classroom, a process manifested largely by the teacher, who is not devoid of personal values and ideas.

In this context, Nilsson (2008) emphasizes that familiarity with the subject being taught may make it easier for the teacher to relate daily phenomena to teaching material and to approach the subject from a variety of angles. However, it is not enough to know the subject (matter) itself. Such knowledge must always be related to other domains, such as that of pedagogical knowledge. These concepts proved useful for survey projects that sought to assess the impact of innovations in the science curricula (Pintó et al., 2003; Pintó, 2005; Couso, 2008, 2009). In more general terms, survey results inform us about the difficulties and challenges present in situations that involve curricular innovations, regardless of whether they are restricted to a change in content or the result of new didactic and methodological guidelines.

In Brazil, many literary works on the teaching of science (Ostermann & Moreira, 2000; Brockington, 2005; Siqueira, 2006; Lawall et al., 2010) indicate the need for both innovation in and updating of the physics curriculum. Those surveys also point to factors that complicate the insertion of modern and contemporary physics in the high school classroom, such as the lack of appropriate materials on such contents, the mathematical formalism present in the theories, and inadequately-trained teachers. Among those aspects, teacher training stands out, since recent surveys point to the overriding role of the teacher in the context of curricular reformulations or innovations. In a curricular innovation process – which often begins in universities – the teacher, using his or her knowledge of a particular school context, transforms, modifies, and adapts the innovation in the best possible way for it to be within the reach of the students in a given school reality.

According to Davis (2003), innovative curricula and methodologies require dealing with several problems and taking on risks, including the possibility of failure(s). Fullan and Hargreaves (1992) claim that one of the risks in this process has to do with to the lack of support and/or the lack of understanding of the proposed innovation on the part of teachers, which can be a delicate matter in any curricular innovation process. When the impetus for change comes from within the teaching system, the chances of success increase. In that case, teachers do not sense change as an imposition (Terhart, 1999). Otherwise, teachers' perception regarding their capacity/ability to innovate and to take on the resulting risks mitigates against the implementation of innovations (Lang et al., 1999).

In that perspective, some authors (Huberman, 2000; Fuller & Bown, 1975, Kagan, 1992) analyze the professional development of teachers in stages or phases, defined as changes that take place as time goes by in aspects that define their behavior, knowledge, self-images, beliefs, or perceptions. In this context, the teacher plays a major role in the process of changing school knowledge, from its origin until it reaches students.

The main focus of this chapter is to analyze teachers' professional development based on Huberman's studies, and to try to answer a few questions about teacher training through teachers' participation in a project of curricular innovation in modern and contemporary physics.[2] First, we present our analyses of a group of 12 physics teachers, henceforth called instructors, who participated in the production and implementation of Teaching and Learning Sequences, and of a second group, henceforth called course attending teachers, who attended an ongoing training course taught by the first group. In addition to questions about professional development, teachers in both groups answered questions about their motivation for participating in these innovation groups, as well as about changes in their practice and difficulties in applying these contents in the classroom.

Professional Development

The idea of professional development as related to teacher training emerges in several theoretical approaches. According to Tardif (2007), the development of professional learning is tied both to its sources and places of acquisition, and to its moments and phases of development. These different factors may be considered when one analyzes a group of teachers participating in a project for the innovation of physics contents in Brazilian high schools. Therefore, learning does not refer only to the learning work itself, but also to the whole process of a teacher's work, which only makes sense when it is related to the actual work situation (Tardif, 2000). It is in the latter context that learning is developed, built, and mobilized.

In general, professional development may be understood as the process by which teachers increase both their knowledge and their competence. It takes for granted that throughout their careers teachers must maintain a permanent investigative attitude, seeking solutions for their problems through questioning and learning. The main purpose and central goal of these actions are the improvement of teachers' educational practices and, consequently, the improvement of their students' learning. Therefore, professional development is a process, rather than an event or series of events. For some people, this process might seem linear, but for others there are levels, regressions, blind alleys, moments of impulse, and discontinuity (Huberman, 2000).

To accept the existence of such dynamics in the professional life of teachers requires us to accept, as well, that different paths may be taken. In one scenario, a given teacher's success may lead him or her to a constant "search" for improvement and professional development. Another teacher might abandon the occupation – or remain in a situation of "inertia" in the face of education's many demands and commitments (Arruda, 2001).

Seeking to understand the professional trajectories of teachers, Huberman (2000) has been verifying the possibility of characterizing "periods" and "phases" in teachers' careers. The establishment of phases or even periods in the career of teaching professionals is known to be a risky endeavor (Tardif 2007, Huberman 2000). The professionalization of teachers is permeated by discernable aspects, such as knowledge acquired, and the following of certain rules and laws. These more tangible dimensions of teaching activities could be used as controls and are, therefore, suitable for objectivization in terms of features that could lead to the identification of phases. However, other aspects related to teacher performance are hard to characterize, such as the criteria used to make real-time decisions in the classroom, to assess, to solve conflicts, to choose methodological strategies, etc. These features are as important as the former for occupational success, and we believe that they, even more than the former, often ensure successful learning for students.

Aware of the problems that every researcher committed to approaching the occupation of teaching as a research topic faces, Huberman (2000) insists on the many difficulties present there. He warns about the risks of the researcher being drawn to simplified or deterministic interpretations. With such concerns in mind, the author presents several procedures that may help in facing such difficulties:

> [I]t is very difficult to study the professional life cycle planning to extract profile types from it, as well as sequences, phases or determinants of either a happy or an unhappy outcome. It is particularly risky to integrate, in the same group, individuals who seem to share common traits, but whose background

> or social environments are different. There would certainly be intersection zones among these individuals, but also difference zones without the boundary between both zones being clear. That reminds us of the biblical proverb according to which there are men who look entirely like other men, men who are similar only in some ways and men who do not look at all like anyone else. Where do those intersections, those intersection zones meet? How is it possible to identify them in reliable terms? (Huberman, 2000, p. 54)

Keeping such parameters in mind, Huberman (2000) nonetheless proposes five phases that mark the evolution process of the teaching occupation: (1) Career Entry (from 1 to 3 years in the occupation); (2) Stabilization (from 4 to 6 years); (3) Experimentation or Diversification (from 7 to 25 years); (4) Search for a Stable Employment Situation (from 25 to 35 years); and (5) Disengagement (from 35 to 40 years of occupation). The author claims that a teacher's career goes through sequences that determine those phases throughout his professional life. However, he emphasizes that not every teacher goes through the phases in the same way, nor do all professionals necessarily go through all phases, and also that the same professional might go through some of these phases more than once. This becomes clear when he states:

> (…) such sequences relate to many, sometimes even to most elements of a studied population, but never to that entire population. (…) There are people who "stabilize" early, others stabilize later, others who never stabilize and there are still others who stabilize and later destabilize. (Huberman, 2000, p. 37)

Next, we highlight the main features of each phase proposed by Huberman:

PHASE 1: Career Entry (from 1 to 3 years in the occupation) – Early in his or her career, the teacher gets to know, for the first time, the pedagogical reality analyzed during academic training. Through this clash with reality, the teacher undergoes an experience of survival and discovery, in an adaptation phase in which s/he, sometimes enthusiasticly, constantly evaluates his or her teaching practice.

PHASE 2: Stabilization (from 4 to 6 years in the occupation) – In the stabilization phase, the teacher creates his or her professional identity; this a decisive developmental stage. The characteristics of stabilization are the security, freedom, and autonomy acquired by the teacher. Phase 2 includes the affirmation of the "teaching self" among more experienced fellow teachers, and a strong commitment to the development of the occupation.

PHASE 3: Diversification and Experimentation (from 7 to 25 years in the occupation) – Having consolidated their pedagogical "competence", teachers participate in a variety of personal experiences, diversifying their didactic material, their means of evaluation, their approaches to working with students, and their ongoing classroom programs, as they search for more authority, responsibility, and prestige. In this phase, teachers are presumably in their most encouraged, most dynamic, most engaged modes, whether in the classroom or on pedagogical teams or in reform initiatives; this can lead to teacher ambition vis-à-vis administrative positions, resulting in some teachers moving away from the classroom "routine" as a consequence of the search for new challenges.

PHASE 4: Serenity and Relational Distance (from 25 to 35 years in the occupation) – This phase can also be understood as a search for a stable professional situation. Either teachers reach serenity and move away from students in relational terms, working in a repetitive way, without many pedagogical changes, or they take on conservatism and complaint, resisting innovations and becoming, on the professional level, both nostalgic and frustrated.

PHASE 5: Disengagement (from 35 to 40 years in the occupation) – By the end of her or his career, the teacher disengages from school matters, devoting much of her or his time to personal projects.

Therefore, the development of a career is a process, rather than a succession of isolated events. The phases are not rules. They may take place or not and, even if they do, the sequence will not be the same for all, since each individual operates in a different professional environment and has different personal and professional backgrounds (Huberman, 2000). The classroom matters of a given classroom and the unique problems faced by each teacher are part of their personal development process and establish what each teacher becomes.

Hewson (2007) believes that the teacher is the main key to improving any curricular proposal. When one analyzes professional development, one must take into account both the personal and the social aspects, bearing in mind how such development takes place within the classroom.

Methodology

The establishment of research and extension groups that involve high school teachers is of major importance in reducing the distance between universities and those schools (mainly public schools) which lack the ability to offer a quality education and teachers that are prepared for the challenges they will face.

In our research project, a group made up of six teachers from the public schools of São Paulo State was established to work in a curricular innovation project studying the insertion of modern and contemporary physics (MCP) contents, beginning in 2003. Once the first proposal[3] was structured, teacher reports served as orientations for future changes. Those reports were crucial for our proposals, since it was possible to adapt the latter based on the teachers' practices in order to reach a final version of each. The byproducts of that work included a variety of teaching materials, presentations in both national and international conferences, scientific articles, and master's theses in programs of the University of São Paulo.

The group was renewed in early 2007, when six new teachers became members. All 12 teachers (six from the original formation and six new ones) have teaching degrees in physics. The new teachers validated the activities to be used in high schools and carried out the developed sequences in their classrooms.

A new project, the goal of which was to supplement the teaching and learning sequences by means of activities with the "instructors" began in 2008. With a focus on MCP contents, we set the goal of supplementing both the teaching and learning of physics in high school contexts, with a view toward contributing to the updating and improvement of physics teaching and learning. This project was materialized through the development of new teaching methodologies (teaching by investigation, teaching by models, teaching about the nature of science), new teaching materials (activity and experience guides, texts, animations, simulations, and digital resources), and resources offered by new information technologies (distance virtual tutorships, distance teaching platforms for teacher follow-up, and dynamic gateways for making didactic materials available).

In this new project, the team in charge of each of the courses was made up of two public school teachers, the "instructors", and university members (professors, undergraduates, and graduate students). The group of instructors was made up of the São Paulo State public school teachers who had participated in the research group and been awarded scholarships from the Foundation for Research Support of São Paulo State (FAPESP). The project consisted of three ongoing training courses offered in three editions. The first one took place in the first semester of 2010, the second one took place in the second semester of the same year, ending in early 2011, and the third one took place in the second semester of 2011. The courses addressed such themes as relativity, spectral lines, and elementary particles, and were offered to public school teachers, henceforth called "course participant teachers". They were trained by means of both in-person and distance activities, collaborating both in the suitability and in the extension of the teaching materials already produced.

Each course has two modules: the first consists of five in-person meetings, in which contents are presented and activities are discussed; in the second, teachers apply a teaching sequence in their high school classrooms. The need to deal with the development of teaching materials and activities adapted to high school and the teaching-learning process were decisive factors in choosing a qualitative study method since "(…) the starting point of qualitative research is complexity" (Gonçalves, 1997, p. 107). Erickson (1998) ratifies such a choice when he states,

> The main goals of qualitative research are to detail the conduct of daily events and to identify the meaning that these events have for those who participate in them and for those who witness them. (…) Qualitative research on education is especially suitable when you want to obtain detailed information on implementation and to identify nuances of the subjective understanding that motivates various participants. (p. 1155)

Cohen and Manion (1980) established several data triangulation strategies that help to confirm findings in qualitative research. Their process of Methodological

Triangulation is represented by a diversity of research instruments and records when data is produced. Thus, it is about the use of different study methods in the same research object.

Therefore, we used a triangulation in our data collection (recordings, interviews, and questionnaires). We believe that this may have enabled us to obtain more accurate data and conclusions. Interviews were held with the teachers in order to try to map their impressions and ideas regarding obstacles, difficulties, motivations, and other influences that they encountered during their training and their application of the didactic sequences. In addition, we used a questionnaire for the construction of teacher profiles and to supply information for conclusions to our hypotheses. Interviews were done by neutral parties who did not belong to the group, and who had participated neither in the development of the material nor in the application of its activities.

There were no strict requirements in the order of the interview questions, and it was understood that the information obtained might in fact lead to new questions, since, when one intends to completely comprehend a given social phenomenon both reorientations and adaptations may take place as information is collected and analyzed (Richardson, 1985).

Discussion of the Results

When we analyzed the interviews, we sought to highlight episodes that could characterize both the instructor teachers[4] and the teachers who participated in the later courses in the phases proposed by Huberman (2000). We also investigated those that indicated (a) the motivation to attend innovation groups; (b) a better understanding of innovation, highlighting professional development and the changes in practice that occur when working with curricular innovation.

i) *Instructor Teachers:*

In 2009, interviews were held with the teachers who had participated in the early phase of the project, including the elaboration and application of the proposal between 2003 and 2005. Although these teachers made up two different groups of six, all 12 worked with curricular innovation. At the moment of the implementation of the proposals, the teachers were all public-school physics teachers from São Paulo State. Therefore, we decided to characterize them as a single group. In order to differentiate each one of the teachers, we numbered them from 1 to 12. This data collection took place in the second semester of 2008 and in the first semester of 2009. The interviews were both filmed and recorded, and lasted between 20 and 80 minutes.

The answers obtained in the written questionnaires revealed that ten teachers were in the Experimentation or Diversification phase, while Teacher 4 was in the Stabilization phase, and Teacher 11 was in the Serenity and Distancing phase, according to their respective service times and the phases established by Huberman (2000). However, not all teachers fit into the phases that Huberman proposed, as the author himself predicted. Teacher 1's report on his practice is incompatible with the Phase 3, or Experimentation, status indicated by his service time. When asked about his participation in the group and what led to that participation, he claimed that he sought security, as indicated in his statement:

> Teacher 1: (…) if they ask something else, you are ashamed to say you do not know. It is hard, you cannot say you do not know. If you say you do not know, your class is over, your year is over, everything is over.[5]

One can observe this teacher's insecurity, even as he tries to keep his students under control and to demonstrate confidence. According to Huberman, such an attitude characterizes the transition between the phase of Career Entry and that of Stabilization. Therefore, it is remarkable in someone who has been a teacher for 15 years.

Later, Teacher 1 admitted once again that he is insecure. When he was asked about his motivation for participating in the curricular innovation group, he made a before-after assessment. His response clearly revealed his troubles in class development:

> Teacher 1: Before (…) I did not talk, my opinions, you know, I was really scared, I was more insecure, so I did another class like that,…from the book to the blackboard and from the blackboard to the book…, that exercise,…, it was nothing more than that, …it was really very limited.

In this passage, the teacher is clearly more concerned about himself than about didactic goals. This characteristic often belongs to the Career Entry phase.

In the case of Teacher 4, the opposite took place. According to his service time, he should have been in the Stabilization phase. However, his report showed a secure teacher, able to make methodological adaptations and diversifications, which revealed characteristics of the Experimentation phase. This was noted when he was asked about his motivation for inserting modern physics into the program:

> Teacher 4: (…) Earlier, my notion of modern physics and teaching, I imagined how to teach any other concept of physics, such as those traditional forms, I had to try not to go so deep into the traditional, it was hard for me to imagine modern physics other than through the traditional bias. I thought more about an adaptation, and here [with the research group] I realized that there is a completely different possibility, I got more aware of the notion of didactic transposition, I think I changed my point of view regarding how to teach both modern and traditional physics.

Later in the interview, Teacher 4 showed he was secure enough to attempt to diversify his didactic material, and possessed the dynamism and motivation necessary for trying out innovative contents, all characteristics of the Experimentation phase. In turn, Teacher 1 showed the opposite: insecurity, "fear", doubts that are often typical of the Career Entry phase. However, he fluctuated from these to perspectives more typical of a teacher in the Stabilization phase.

A. Motivation for Participation in Innovation Groups
Early on, there was an attempt to verify the reasons behind participation in groups working on innovation projects. Some of the statements are revealing.

> Teacher 4: (…)Well, I was always very interested in modern physics, since my undergraduate days, indeed before then…to be honest physics at school never attracted me very much, I liked it, I had good grades, but when I read *A Brief History of Time*, by Stephen Hawking, (…), I recall that at that time those things about modern physics that called my attention, what makes the eye glow is modern physics (…).

> Teacher 5: (…) As teachers, we always want to recycle. Every opportunity you have to recycle, to learn something else, to innovate within teaching is always welcome, I think it is a real opportunity, I saw an opportunity to grow (…).

In the transcriptions above, Teachers 4 and 5 make it very clear that their participation in innovation groups took place due to a moderate dissatisfaction stemming from their desire to introduce new methodologies, and from their disengaging from the classroom routine as a consequence of their search for new challenges. Routines imposed year after year in the school context are seen by some teachers as counter to good teaching. Other statements seem to reinforce that affirmation, as will be verified later.
Asked about the subject of MCP, Teacher 7's expectations had to do, initially, with the subject taught, with didactics, and with class preparation:

> Teacher 7: (…) it was basically for the function of going to school, not initially, later I started to like modern physics, in the beginning it had more to do with that idea of elaborating the activity, going to school, and coming back (…).

Teacher 7 seems to demonstrate that he wants to consolidate his pedagogical competence, as acquired over time and with work experience. Increasing mastery may lead to possibilities opening for the development of teachers' own learning experiences; this may be tied to greater security and to feelings of proficiency on the part of teachers, enabling them to insert modern physics contents into their high school classrooms.

B. Changes in Practice and in Professional Development When Working with Curricular Innovation
As far as the second theme of the interview, change in practice, was concerned, most of the interviewees believed that their participation in curricular innovation groups contributed to changes in their practice. Some statements indicated this perspective:

> Teacher 2: (…) the change that I had was to favor physics, even though I have a traditional way of teaching in the more qualitative, rather than in the quantitative sense (…). Therefore, I go into my classes trying to offer the

> student a more qualitative physics as far as possible, one that is more human and closer to reality. In addition, I have had positive results. This makes the students interact more, I notice that they interact (…).
>
> Teacher 3: A long time ago, we used to stay, to a certain extent, in that stagnation… with no prospects at all… Of course, I always try to renew my knowledge. Once in a while, when there was a course, I attended it, but nothing that clicked, that motivated me. (…) We had to come up with a reading strategy so that it did not become boring. I discovered that gradually. In one class it worked, while in another it did not.

Teacher 2 indicated changes in the way he addresses content, while Teacher 3 sought to try new strategies. Security allows for greater flexibility, which leads teachers to vary material and even didactic sequences, typical characteristics of the Diversification and Experimentation phase. During this phase, the teacher feels ready to face either complex or unexpected situations with the ability to maintain control. According to Huberman, the teacher is more secure, more at ease, throughout that phase, having found her or his own teaching style. This leads to greater self-confidence and to mastery of the many aspects of the work of teaching, which is reflected in teachers' professional balance. In that sense, to stabilize means to enjoy a higher level of personal and occupational freedom. Still, regarding changes in attitudes and teaching practices, other statements reinforce earlier comments:

> Teacher 4: (….) I think so, when I think about an activity I try to look at it in another way, not simply as I used to look, earlier I guess that I thought more about the content, now I try to look at other things, but it actually caused an effect on me.
>
> Teacher 5: Oh, I noticed a radical change (…), even more so because I also had a personal change. I had to study many things I did not know (….) I believe that I started to look in a different way at the possibilities for developing content, for developing a curriculum based on other matters, (…) because when you want to develop the skills and competences of the students, you want them to become that citizen who will read, interpret, argue, and be critical. If you choose a content in which he is not interested, it is more difficult, and they find modern physics content interesting, even due to the attractions of the media, and to the things used in daily life.

Teachers 4 and 5 try to diversify both their methods and their practices and to figure out the most appropriate ways to apply them in teaching, which clearly shows that they are in the Diversification and Experimentation phase, in which teachers are motivated and energized toward innovation and disinclined to engage in routine classroom practices.

These interviews revealed that when teachers participated in our research groups they experienced changes in their practices, became more secure and self-confident, and also changed their ways of thinking about teaching MCP, even though the precise contribution, as provided in their elaboration of the didactic material produced, is not clear. In any case, they felt prepared to enact such innovation. By participating in the group, they overcame obstacles to appropriating the proposal as they wished, as the following statements suggest:

> Teacher 5: (…) I think I started to look in a different way at the possibilities for developing a content, for developing a curriculum from other matters (…).

> Teacher 10: (…) an investigative material is a real material for the classroom, that can meet the needs of the teachers who are in the classroom as well as those of the students. The use of the laboratory is a correction of the language, a change in the language, from daily life to more scientific language, among other aspects not present in the pedagogical material.

Therefore, Teachers 5 and 10 are able to undergo the personal experiences characteristic of the Diversification and Experimentation phase. Teachers often tend to accede to group values. They share their professional experiences with other members and exchange knowledge with them on various matters. Teachers 2 and 6 diversified their class management, since they went after new challenges when they participated in the innovation groups:

> Teacher 2: (…) so, as far as the approach was concerned, I do not know, you gradually developed it with the students, they gradually noticed it. You don't explain what it is. He will reach the conclusion by himself (…).

> Teacher 6: (…) because it is not only an expository class, an exclusively expository class, they have to work a lot, attend the classes, fulfill several activities, and they think this is strange (…) you elaborate, you can participate in the development of knowledge, they have a very innocent idea (…).

These responses show teachers who are invested in their own development, seeking to diversify their methods and practices and to find the most appropriate ways to apply their learning in their teaching, as identified in the Diversification and Experimentation phase. According to Huberman, one phase may prepare a teacher for the next and may limit the range of possibilities that may develop, but sequencing cannot always be definitively determined. The search for new challenges is a response to the fear of falling into a routine, and engagement with collective activities corresponds to a need to maintain enthusiasm for the occupation.

As far as whether participation offered contributions to professional development, almost all the interviewees answered in the affirmative. However, engagement level varied. While some indicated a critical analysis of their practices, others carried out modest changes, as some statements point out:

> Teacher 2: (…) so, as far as the approach was concerned, you gradually developed it with the students, they gradually noticed it. You don't explain

> what it is. He will reach the conclusion by himself. And then he often left with… he entered without knowing what was going on… what would take place, but he left with questions.
>
> Teacher 5: (…) I think I started to look in a different way at the possibilities for developing a content, for developing a curriculum from other matters (…).

Here we notice that Teacher 2 has an open-minded stance in relation to his class. He is not afraid to "experience" new approaches, because he seems to be secure about any diversifications he may initiate in the classroom. One may note in Teacher 5's statement that he is not afraid to change the curriculum. In other words, both teachers are willing to incorporate new contents, materials, and approaches. This corresponds to their professional development phase, according to Huberman's categories, that of Diversification and Experimentation.

Most teachers' statements revealed an engagement with collective activities, which corresponds to a need to maintain enthusiasm for their occupation. Here, it seems clear that teacher participation in the curricular innovation group led to personal and professional development, indicating that they were in the Stabilization and/or Diversification phase. This is related to what Couso and Pintó (2009) conceive as the ability to learn in their environment, which entails the possibility for participating in social interactions that produce professional knowledge and for internalizing this knowledge as a result of participation in cooperative work. However, there were cases in which there was a departure from the phases that Huberman pointed out. We can verify that in the following statement:

> Teacher 1: So, because I got tired, because I did not want to stay only that way, I did not want to be that static teacher, only standing there, only alternating between the book and the blackboard. A teacher must talk, he must know what is going on with the student, he must also find out about the students, encouraging them, training them, teaching a good class. In that case, all students participate and you do not even feel the class go by (…).

Teacher 1 makes explicit that his concern has shifted to didactic goals, since he feels more at ease in facing complex or unexpected situations, generating a bet, in the middle or long run, on security and a greater flexibility in class management. Those traces of professional development place him in the Stabilization phase, even though he has been teaching for 15 years.

ii) *Teachers Who Participated in Courses*

Our courses took place at the School of Education of the University of São Paulo (FEUSP) and were attended by 226 teachers, each of whom answered our questionnaire. The themes of the courses were: relativity, spectral lines, and elementary particles. The courses were offered three times.

The answers of 194 teachers, from three different classes, were analyzed. The first class had 80 teachers, the second one had 79 teachers and the third one had 34 teachers. As far as professional profile was concerned, the first issue analyzed had to do with professional training, taking into account the information obtained in the questionnaire from the beginning of the course regarding professional training, attendance in courses on curricular innovation, and total years of teaching. Responses showed that 62% of the teachers were physics graduates, 22% were mathematics graduates, 3% were chemistry graduates and 6% were graduates from other disciplines, primarily engineering. This makes sense, since the main requirement for a teacher to attend this course was for him or her to be a classroom teacher of physics in public schools. Regarding professional qualifications, it was verified that 36.5% had taken post-graduate courses; in other words, many of the teachers had chosen to continue their education, as evincing ongoing efforts to learn more and to develop their careers.

Regarding attendance in ongoing training courses, it was observed that 76% of the teachers had already attended at least one course in the past five years, demonstrating their interest in remaining updated as far as teaching is concerned. According to TARDIF, “Therefore, professionals must train and renew themselves through different means, after their initial university studies” (2007, p. 249).

We used Huberman’s theory with the goal of sketching the professional development profiles of the teachers, dividing them into phases according to their teaching time. These phases are not rules, and may or may not take place as outlined. According to our analysis of the answers of the 194 teachers who took the course, most of them, indeed 61%, were in the Diversification and Experimentation phase (7 to 25 years of teaching), which is characterized by the teacher’s desire to innovate in the classroom, since s/he feels secure and stable. Teachers in that phase are supposedly “the most motivated, the most dynamic, the most engaged in pedagogical teams” (Huberman, 2000). Analysis of the questionnaire also indicates that 11% of the teachers were in the Career Entry phase; 21% were in the Stabilization phase, in other words, they were still getting used to the school life; and 4% were already in the Serenity and Disengagement phase, that is, getting ready for retirement after having been in the classroom for more than 25 years. This latter reveals that the Huberman’s phases are not rigid rules, since those teachers still attend innovation courses, showing interest in innovating and learning new teaching methods.

One can observe a strong commitment to professional development on the part of these teachers, since they remain motivated for and enthusiastic about the occupation. As can be observed, 21% of the teachers were in the Stabilization phase and 61% in the Experimentation and Diversification phase. Huberman (2000) claims that in these phases the teachers are at their most concerned with and committed to the development of the occupation. They are also the ones who attend the most training and updating courses (such as this training course and curricular innovation group), leading to personal and professional development.

The eight teachers who attended more than one edition of the training course were interviewed. The teachers in this group have been teaching between two and

16 years. Three of them were licensed in physics, three in mathematics, one in science, and one was an electric engineering graduate. In order to characterize each of the teachers, a reference acronym was established: C1, C2, C3…C8.

The major themes that guided the interviews were the same as those presented to the instructors:

A. Motivation for Participation in Innovation Groups

Initially, the teachers were asked about their motivation for attending the training courses. Four of the teachers answered that it was due to the lack of MCP contents in their undergraduate training and four teachers mentioned the need for updating, as can be seen in the following statements from teachers C1 and C4.

> C1: First of all, regarding my physics training, I got my teaching degree in three years, so modern physics only included relativity. I did not take courses on particles and spectral lines, so that was my main interest.

> C4: It was actually a student (…) and he asked me in 2008: teacher, have you heard about the God particle? (..) So I thought: my God, there is still something I do not know!!! (…) I had not studied MCP in my undergraduate courses and I was facing a situation in which the student asked me something I did not know the answer to.

The statements by Teachers C1 and C4 reveal possible difficulties derived from a lack of knowledge of MCP content, which may be due to initial training in another field, or even to insufficient training. It is not surprising that this motivates teachers, since, as Nilsson (2008) highlights, gaps in teacher knowledge may lead to feelings of frustration and discomfort, even more so when a student asks a question to which the teacher not know the answer.

Teachers also expressed the need to update and to learn "new practices". According to Tardif (2007), to learn is to acquire knowledge, and from there to build knowledges that are tools for work development. Teachers gradually learn how to teach by facing, on a daily basis, situations that enable them to build such tools.

B. Changes in Practice and in Professional Development When Working with Curricular Innovation

The teachers' answers revealed that they changed their practices after they attended the training courses. They reported that, in addition to presenting MCP contents to their students, they now use the methodologies learned in the courses to teach other physics contents. According to teachers C2 and C3, classical physics is no longer framed as undisputed truth, since they now call students' attention to the history of science and to physics as a human development.

This is of great importance for student education, since it presents a more correct view of science and of the nature of scientific work, overcoming the linear view of scientific development currently present in most textbooks and physics classes (Ostermann & Moreira, 2000).

> C2: Before that was how it happened, that was simply it, as if there was an end (…) today that is not the case. I teach classical physics not as the end, but as part of a process.

> C3: What I have been noticing a lot is that I have been giving a little more attention to the philosophy of science (…) how does the person arrive at that concept, that thing about not being an undisputed truth.

Such changes in teachers' practices are a reflection of the professional development provided by the courses. This process improves both the knowledge and the competences of the teachers, providing them with a permanent inquisitive stance, and encouraging them to always seek solutions for their problems by means of questioning. In this way, teaching practices evolve and improve; moreover, and above all, student learning does the same as a consequence of this progress on the parts of teachers.

When professional development is debated one must take into account what it means to be a professional and to what extent professionals have the autonomy to carry out their work. It is a long-term process, in which different kinds of opportunities and experiences interact, and both learning and teaching are produced. It is the evolution of the professional self over the course of a given career.

iii) *Difficulties of Instructors and Course Participants*

When instructors were asked what they would characterize as the difficulties of teaching the course to the attending teachers, two categories were identified: one had to do with knowledge of the contents presented and the other with teaching methods and strategies. Teacher 6's statement reveals that the initial concern was with knowledge of MCP content:

> Teacher 6: Once this stage of the course was over, I considered that my greatest difficulty was my training in modern physics. (…) As I prepared my classes, I was almost exclusively concerned about the contents, leaving aside how to deal with them in the classroom.

Even though he participated in the group preparing the material, his concerns remained when presenting it to those who attended the course. However, one can later detect issues with his pedagogical training that need to be addressed for his classes to improve.

> Teacher 6: I am certain now that a new approach is necessary for me to carry out my work, taking into account such issues as problematization, appropriate didactic sequences, didactic transposition, etc. (…) exchanging experiences with my fellow teachers was also very important for my ongoing training as an education professional.

Here we can verify that teachers' concerns had to do not only with contents, but also with the methods and strategies they could use to work with MCP content in high school. One can identify two different levels of knowledge, represented here by a combination of knowing the subject and knowing how to teach that subject. In didactic terms, this is close to the notion of Knowledge of Pedagogical Contents which, according to Shulman (1996, p. 9), includes “the most useful ways to represent ideas, the most important analogies, illustrations, examples, explanations and demonstrations, in short, the way to represent and to formulate the subject to make it more understandable”.

The main complaints of the teachers who participated in the courses regarding introducing MCP contents in the classroom had to with the lack of structure in their schools, a shortage of materials for differentiated activities, and difficulties finding the time to study, prepare, and present the activities.

> C1: (…) It is actually about structure. In the suburbs, we do not have a laboratory, nor do we have it downtown (…) and I have to take what I need to use in terms of audiovisual resources (…) I have to schedule it ahead of time, sometimes I have to prepare everything and we have a very limited time to do all that alone.

> C7: (…) The greatest difficulty is of a material nature. It is hard for us to implement due to the lack of materials, we have to buy them (…) An issue that seemed more troublesome to me was that they are not used to that kind of activity. Therefore, they say everything at once, they want to participate, they participated actively (…) they can’t behave themselves.

The difficulties mentioned by the instructor teachers[6] and those who participated in the courses[7] are very similar, regardless of the activity concerned. However, the latter attempted to adapt the material according to the reality of their schools and classrooms.

As far as the participation of the teachers in the project was concerned, both the responses of the instructors and of those who attended courses contributed in a significant manner to changes in teaching practice. Changes in teaching practices resulted from the debates, studies, and explanations that the courses provided, which strengthened the knowledge that the teachers had about certain subjects, both in the contents of the discipline of physics and in the pedagogical methodologies and strategies presented. This process in turn provided the necessary security and support for teachers to innovate in the classroom.

The participation of the teachers in the training courses was a significant factor in their support for the proposal, since, while they did at the outset accept this challenge, they later became in an important sense the owners of the didactic material, with different levels of initiatives intended to facilitate adjustments, adaptations, and reorientations based on their work contexts.

CONCLUSION

For our initial work, the phases Huberman proposed served as decent descriptions of the professional life cycles of teachers, since they delineate the phases, transitions, and crises which teaching professionals must face throughout the development of their professional careers, phenomena which affect many, even most, teachers. This model is an overview, which groups tendencies that are not so ordered in the real world. We cannot in fact say that all professionals undergo the same phases, in the same order, regardless of living or working conditions, historical period, immediate social interactions, and individual desires and needs.

Teacher statements revealed that the lack of MCP contents in their undergraduate educations and their searches for new practices were the main incentives for them to attend the training courses. Even teachers who had teaching degrees in physics reported that what they learned in the university, during their undergraduate courses, was not enough to address different MCP topics in high school classes. Since the lack of knowledge of those contents leads to insecurity, discomfort, and frustration on the part of teachers (Nilsson, 2008), they end up not including such challenging themes in their classrooms. However, despite the importance of and the need for ongoing training courses, we believe that contents and didactic instruments that provide teachers with support for curricular innovation should be offered in their initial training.

It should also be emphasized that teacher support is of the ultimate importance during the elaboration and implementation of innovative proposals, since it is teachers themselves who try to adapt, utilize, and redirect innovative ways of teaching and learning according to their unique school reality. In other words, the teacher interacts and negotiates with innovation, either rejecting or changing certain aspects of the proposal, in the way that s/he considers the most appropriate for the needs of her or his classes and students (Pinto, Couso, & Gutierrez, 2005) in order to actually produce school knowledge. Certain aspects of the subject matter make it more difficult for teachers to introduce MCP in high schools. Even though they are generally able to grasp the contents and activities that the training courses offer, teachers mentioned the lack of school structure and the shortage of time available for preparing and teaching the classes as factors that render the real-life execution of the proposal more difficult.

Finally, we must emphasize the key role played by teachers in the curricular innovation movement. According to Tardfi (2007), university researchers must stop viewing teachers merely as research objects. Instead, they must consider them as subjects with their own knowledge sets, as collaborators and as co-researchers, in such a way that they value their fellow teachers and, at the same time, support their ongoing training.

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NOTES

[1] American Project.

[2] This project was developed at USP, by Professor Mauricio Pietrocola, between 2003 and 2013.

[3] The first proposal taken into the classroom was about the concepts of quantum mechanics. The full course and its analysis can be found in Brockington (2005).

[4] Data on the instructors was presented at the *III Encuentro Internacional sobre Investigación en Enseñanza en Ciencias*, at Burgos-ES, and in the XII EPEF – Meeting of Research in the Teaching of Physics, at Águas de Lindóia, SP, 2010.

[5] The transcriptions were made verbatim. Some bad language habits were removed, without changing the content.

[6] Studies done by Siqueira with the group of instructor teachers confirm these results.

[7] Studies done by Shinomiya with the group of teachers who participated in the courses confirm these results.

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Ivani T. Lawall
Physics Department
State University of Santa Catarina
Brazil

Maurício Pietrocola
Department of Teaching Methodology and Comparative Education
School of Education of the University of São Paulo
São Paulo-SP, Brazil

ALEXANDRE BAGDONAS, ANDRÉ NORONHA, VITOR MACHADO,
FELIPE VELÁSQUEZ, AND IVÃ GURGEL

10. A GAME DESIGNED TO TACKLE CONTROVERSIES ABOUT THE NATURE OF SCIENCE

Debates Regarding Science Funding Based on Studies of the History of Cosmology in the First Half of the 20th Century

INTRODUCTION

Nowadays, the importance of a rapprochement between history and philosophy of science (HPS) and science teaching is almost unanimously accepted among researchers in science education. This can be noted in publications, dissertations, and theses, as well as in in major national and international conferences and seminars (Matthews, 1995; El-Hani, 2006; Vilas Boas et al., 2013; Noronha, 2014; Bagdonas, 2015). This shows the strength of this research area, as well as the importance attached to HPS for science education, although science curricula in many countries have moved very little in recent years towards effectively achieving a historical-philosophical approach (El-Hani, 2006, p. 5). Naturally, there have been many developments in the area of research and analysis of HPS-related topics, but even major advances should always be regarded with relative caution.

As Matthews (1995 [1992], p. 165) categorically stresses, the disciplines of the history, philosophy, and sociology of science do not have all the answers to the many issues that confront science education today. Furthermore, it is known that HPS may be used for different educational purposes, including those that are unforeseen or unexpected according to recent curricular standards.

Meanwhile, there is a quite large predominance of studies that employ the history of science to discuss nature of science (NOS) topics in the classroom. Currently, a significant portion of these seek to contemplate the so-called "consensus view" of the NOS in science education (Lederman, 2007). Although we consider these studies valid, we argue that openly discussing the controversial issues of the NOS is an important challenge for science educators, one that should not be avoided. In the following section, we will discuss the debates regarding non-consensus about the NOS.

It is currently commonplace for a full scientific education to include processes of teaching that not only aggregate scientific content, but also encourage reflections about scientific enterprise and knowledge, which is known in the literature as NOS. A little less than twenty years ago, the importance of approaching issues related to the NOS in science education became a consensus, as

M. Pietrocola & I. Gurgel (Eds.), Crossing the Border of the Traditional Science Curriculum, 163–179.

noted in analyses of recent articles about science education (Lederman, 2007; Vilas Boas et al., 2013). However, consensus regarding its importance does not imply a consensus on the contents of the NOS. There is no full consensus on the following issues: What is the proper definition of the NOS? What is its content? What is the nature of the NOS?

Recently many authors have philosophically criticized the "consensus view" of the NOS (Irzik & Nola, 2011; Matthews, 2012; Rozentalski, Bagdonas & Noronha, 2012; Bagdonas, Zanetic & Gurgel, 2014; Noronha, 2014, Bagdonas 2015), especially the one established by Norman Lederman et al. (2007). Given the complexity of science in general, we believe it is too risky to evaluate conceptions about NOS as "right" or "wrong". The criticism extant is mainly directed toward the dogmatic assumption of a list of NOS tenets which does not show the variety of features of different sciences. It proposes the consideration of (non-consensual) issues such as the role of mathematics in science, scientific realism (Matthews, 2012, p. 20; Noronha, 2014), the criteria used for science demarcation, the relationship between science and religion (Bagdonas, 2011), the "social construction" of science (Greca & Freire Jr., 2004; Rozentalski, Bagdonas, & Noronha, 2012), and so forth. We argue that bringing scientific-philosophical controversies to science teaching may enable a deeper understanding of the characteristics of science, since such factors were almost always present in the history of science (Matthews, 1995, 2012). The diversity of philosophical positions which might possibly manifest in discussions on controversial NOS issues is extremely interesting to the teaching of physics, for at least two reasons: it mirrors, in its own way, the diversity of philosophical positions among scholars of science and scientists, and it allows for reflective, non-doctrinaire education about scientific knowledge and enterprise.

RELATIVIST CONTROVERSIES AND THE CONTRIBUTIONS OF SOCIAL HISTORY TO SCIENCE EDUCATION

Several "anti-scientific" movements have emerged and gained strength over the last few years. In general, most of these argue on behalf of what can be generically called "epistemic relativism", a posture with several branches. In its most extreme versions, it maintains, for example, that nature and society cannot be separated in any domain, in such way that "natural events" are defined as "socially-constructed events" (Pessoa Jr, 1993, p.9). Notions such as "truth", "reference", and "ontology" are relativized. These tenets directly attack the scientific realist belief that scientific knowledge refers to the exterior, mind-independent world (Chakravartty, 2013, p. 19). According to the philosopher of science Boghossian (2012, p. 44), many people today are drawn to relativist conceptions, even though some of them entail very extreme implications. These tensions are often translated into conflicts over the value of science.

By contrast, according to the historian of science Shapin, "anti-science rioters" have much to learn by listening to scientists and their views about scientific practices and knowledge, since they can point to criticism from within (Shapin, 2012, p. 17). Likewise, scientists also have much to learn about their own discipline with the help of historians, philosophers, and sociologists of science. A broad appeal for philosophical plurality is emerging, which seeks contributions from many different perspectives about science and the history of science.

This appeal can be transposed to the aims of science education, in order to defend philosophical pluralism in such contexts (Rozentalski, Bagdonas, & Noronha, 2012; Noronha & Gurgel, 2014). Presently, the vast majority of research holding the so-called "consensus view of the NOS" about students' conceptions of NOS concludes that the one widespread belief that needs to be problematized is that experiments can be used to prove that certain theories are true. Gil Perez et al. (2001, pp. 129–134) call this an "empirical-inductivist view", which "highlights the role of neutral observation and experimentation, leaving no place for the essential role of hypotheses as a research guide, as well that of theories available in order to guide the whole process".

To defend the approximation of the controversies of the NOS to science education is to both critically regard different philosophical standpoints such as those above, and to contend that many of them can provide interesting contributions to the field of science education. On the one hand, it is important to avoid a rigid, anti-historical, linear view of science, in order to prevent the transmission of a deformed image of science as a decontextualized and socially-neutral enterprise. This approach contributes nothing to the formation of more critical and responsible citizens. Secondly, it is necessary to try understand that discussions such those generically called "postmodernist" can enrich debates about science by providing a more realistic picture of the multifaceted phenomenon that is science, and that is useless simply deny or attack them (Greca & Freire Jr., 2004, p. 347). However, certain caveats must be made about what is and what is not worth including. Simplified historical conceptions, as in certain radical or naive philosophical positions, have been condemned over the years in the literature of science education, and should therefore be avoided. However, intermediary and critical positions may offer important educational contributions, either at the high school or undergraduate level.

The complexity of the epistemological discussions set forth in science education may take a progressive route, from early childhood education, incorporating simpler and less controversial topics, to teacher education, when important philosophical and historical tensions need to and can be explored (Abd-El-Khalick, 2012). We have developed a tool – the implementation of which we have analyzed below – which explores, within a structure of didactic development, the tensions and manifestations of political and sociological influences on science and scientists in their particular contexts: the Cosmic Game.

THE COSMIC GAME

Several researchers have argued that using games in science education is a good way to enhance students' interest and engagement in classes (Gee, 2003; Shaffer, 2006; Antunes & Sabóia-morais 2010, Jann & Leite 2013, Oliveira & Soares 2005, Trópia 2011; Brito & Sá, 2010; Matias & Amaral, 2010; Braga & Matos, 2013; Bretones, 2013). Many of these games are didactic strategies intended as improvements to traditional teaching based on memorization, review, or evaluation of scientific concepts. However, with Sabka and his collaborators (2014), we believe that the most promising ones are those that aim at a more radical transformation of science classes, with less attention to the transmission of concepts and more focus on promoting critical thinking about socio-scientific issues. Inspired by the practice and research of educators, we created a game which aims to stimulate students' creativity and imagination, and to thereby promote the development of important skills like collaborative research and teamwork.

The Epistemic Games Group, at the University of Wisconsin, has developed several educational games that aim to develop skills, knowledge, identities, values, and epistemologies that professionals may use to think in innovative ways (Shaffer, 2006). While students play these "epistemic games" in virtual worlds, they are invited to reflect about, and seek solutions for, real-world problems. In this way, they learn to think and act like historians, journalists, scientists, urban designers, and other creative professionals.

One of the most promising strategies for the promotion of critical thinking in science education are games based on debates. This kind of strategy, sometimes called "Simulated Jury", has been used to teach physics (Guerra et al., 2002; Silva & Martins, 2009; Forato, 2009; Ferry & Nagem, 2009), chemistry (Brito & Sá, 2010; Matias & Amaral, 2010), and astronomy (Ferreira et al., 2011; Ferreira, 2013).

In Shafer's (2006, p. 17) version of this game, known as the "Debating Game", students are invited to learn to think like historians via debating the Spanish-American War. In his model, discussions are organized as political debates, and students are cast as either "debaters" or "judges". The judges decide which team of students presented better arguments, thus producing a winner in the game.

Shaffer argued that the biggest difference between the way high school students and historians think is the importance given to information and bias in historical discourse. While students want to memorize a great quantity of facts and see bias as a binary attribute, historians focus on understanding how bias – given that it is an unavoidable facet of knowledge processing – might affect their interpretation of historical sources (Shafer, 2006, p. 30). Therefore, the "Debating Game" is a way to change history classes so that instead of memorizing many historical facts, students are encouraged to think like historians in debates about different possible historical interpretations. Playing this game, students won't really learn the complex epistemology of historians, but they may well develop a more authentic view of history and also enhance other important abilities, such as writing, reading, research, and communication.

The Cosmic Game was developed collectively by science educators in the TeHCo group[1] at the Institute of Physics of the University of São Paulo. Members of the group were high school physics teachers and graduate students, researchers in physics education. The game was also inspired by cosmology courses previously developed by Alexandre Bagdonas, during his master's thesis, supervised by Cibelle Silva. In this project, they developed a course based on the big bang and steady state cosmological controversies of the 1950s, in which they investigated pre-service teacher conceptions of the connections between science and religion (Bagdonas, 2011).

The development of the Cosmic Game included the creation of rules, game dynamics, and materials, mainly cards and a game board. We also planned activities, such as debates or the explanation of scientific concepts, with videos, computer simulations, and other strategies, so that the game became associated with a teaching and learning sequence (TLS). The main goal of this sequence was to promote a richer understanding of the relations between the development of science and its social and historical contexts. For this, game dynamics stimulate research regarding not only cosmology during the first half of the 20th century (mainly 1914–1939), but also the political, cultural and economic influences on science during this period.

In this game and sequence, the general objective is to problematize both the notion of the neutral scientist, free of ideological influences, and a naively relativistic vision of scientists as completely dominated by ideological influences. It is important for the student to understand the development of science as a human production influenced by its social and historical contexts, but not as entirely determined thereby.

This sequence consists of an introduction to cosmology concepts and the three phases of the game, incorporating the search for information related to science and cosmology, development of this material, and debate. The three main phases of the game (detailed below) were developed so that its main activities involve the investigation of those historical events relevant to cosmological development in the period 1914–1939, and discussion of the results of these investigations, facilitating, through this process, a debate around the various relations between scientific development and the social and political history of the world.

One of the challenges faced during the development of this sequence was the management of the requirements both of recent historiography of science findings and of research in science education regarding the inclusion of historical episodes in science curricula (Forato, 2009). Even though the historical quality and precision of the texts and other educational materials developed for this project are very important, for educational purposes, the inclusion of some fictional elements was also beneficial. This helped in promoting a more "playful" and attractive experience for students. However, students were carefully and explicitly told which elements were fictional, so that all others were assumed to be based on true historical facts.

The scenario of the game starts with World War I (1914). The teacher presents him or herself as a representative of the division of Agriculture and Natural Sciences of the Rockefeller Foundation[2]. S/he tells the students that they have been invited to became investigators in a new subdivision: studies about the universe (cosmology). At this time, there were no professional cosmologists, and most scientists who studied this subject were astronomers, mathematicians, or physicists.

The students play roles as investigators in the cosmology subdivision of the Rockefeller Foundation, and are divided into groups of about five individuals. One group has as special role as jury members. The other groups have the goal of traveling around the world to do research and decide which countries and scientists have potential for the development of cosmology so that the foundation can make a grounded decision about its philanthropic funding. After doing research, the investigators work within their groups to formulate a collective argument. In some phases of the game, they must decide which country should receive funding from the foundation. In others, they must choose a specific scientist to receive the money. This discussion is then presented orally to the whole class, so that the jury, having heard the arguments presented by each group, may decide which is best – and thus which group's choice should be funded.

In the introductory stage of the sequence, the first planned activity is a discussion of the meaning of Cosmology, differences between cosmology and astronomy and a debate about the overambitious and challenging goal of trying to understand the universe as a whole. For these videos about scales and distances in the universe stimulate discussions about cosmological questions, like "do you think the universe has always existed or there was a beginning?" The second activity offered a summary of the main political, technological, and scientific events in Europe for the period in which the game starts (the beginning of the 20th century). The main focus is on discussions about economic and technological influences during the development of the Relativity, such as influence of nationalism in science during the Great War. For this, was presented an excerpt of the movie "Einstein and Eddington", which shows the British scientist Arthur Eddington as an advocate of the theory of Relativity, a "German" theory, during a period of intense rivalry between Britain and Germany.

Aside from the introductory stage, each phase of the game is related to a different period (1914–1924; 1925–1931; 1932–1939), and divided into three activities: (1) Investigation (the search for information) and choice of a country to be funded; (2) Summary of the main events of the period (presented by the teacher); and (3) The selection of the scientist who will receive the Rockefeller Award.

In the first activity, groups must vote on which country they feel should receive financial help from the Rockefeller Institution. This naturally leads students to a more contextual debate, with a focus on political and economic influences on science. In the third activity, the groups must vote on a scientist, which leads the debate from context to content (as detailed below).

In the first activity, students "travel" around the world in search of information relevant to the period. This information is obtained by the students via "clues" which have been elaborated for the game. These clues are found on cards which contain specific information related to the game phase period. They are divided by countries, so that a clue for a given country contains information related to this country. Each clue can contain information related directly to cosmology, related to science in general, or related specifically to a relevant political or social aspect of the period and country.

Students must decide which countries they want to investigate from the choices shown on the game board. Each group may have access to a maximum number of five clues (and countries) per round. After taking notes about their investigations, the groups begin to formulate an argument about which country should receive funding. For this, they have the challenge of making their selection from a pool of different and diverse information.

One risk of this phase is that students may try to simply memorize all the names, dates, and facts, which would lead to a very inadequate view of the history of science. Therefore, it is important that, in the second activity, the teacher discusses the most relevant issues in a structured way. The advantage here is that the selection of what is relevant is not made by the teacher alone, or by the creators of the TLS. The students, playing their roles as investigators, also help the teacher in this selection, demonstrating what is most meaningful in their perspectives. In this phase, the teacher encourages discussions around the relations between the social and political context of the period and the development of science and cosmology, and presents the conceptual elements of science related to the period, along with the main scientists who developed research on cosmology.

The third activity is mainly focused on argument and debate. The teacher presents a list of the scientists under consideration for the Rockefeller Award, in recognition for their research during the previous period. Each group must formulate arguments supporting a vote for one of these scientists. As with the other parts of the game, it is very hard to predict what will happen, since the outcome depends very much on the role of the jury, the clues received by each group, and the students' argument-formulating abilities. The next topic of this chapter is a detailed description of these activities in physics classes.

Given that each phase of the game is related to a different period, each contains unique aspects. In addition, the information given to the students was planned in distinct ways which also add complexity. The following is a summary of the most relevant information related to each period.

First phase:

1. Investigation: The card-clues were elaborated in such a way as to encourage discussion about nationalism after World War I, with information about the boycott of German science in the post-war period by French, British and American scientists, the first contact with the cosmological models of Einstein and De Sitter, and the relationship between Einstein and Friedmann.
2. Summary: From the relationship between Einstein and Friedmann, a discussion is presented about "objectivity" in the process of theory evaluation, and the system of peer-review of articles, with a reflection about the possible influences in this process, is also explored.

Second phase:

1. Investigation: The clues in this phase provide students with information about investigations into redshift and Nebula distances, and information about possible interpretations of this sort of astronomical observation, relating these observations to cosmological models of the universe (static and dynamic).
2. Summary: From the contributions of Lemaître and Hubble, discussions about possible interpretations of the redshift and disputes about priorities in science are presented, with reflections on issues such as fame, researcher authority, and nationality. Students encounter the possibility that relationships between researchers in the scientific community, as well as scientists' personal convictions and philosophical and religious conceptions, can affect the process of acceptance of a scientific theory. Another goal is to present studies of the relation between redshift and distance, with analysis of graphs created by several astronomers, using the astronomical observation data available at that time. Students also debated the possible cosmological interpretations of these graphs.

Third phase:

1. Investigation: The clues in this phase contain information about how scientists reacted to the theory of the expansion of the universe. Hubble remained skeptical and held on to the possibility that new explanations of the redshift could be formulated. One such possibility was the "tired light" model investigated by Fritz Zwicky. On the other hand, most scientists interested in cosmology, like Gamow, Robertson, Tolman, and Lemaître, accepted the expansion of the universe. In this period, Georges Lemaître proposed his model of a dynamic universe (in expansion) with a "beginning" in time. Since Lemaître was a priest as well as a scientist, some critics became suspicious that he was impelled to create a cosmological model with a beginning in time because it would be compatible with his own faith. This happened especially in the USSR, where Communist scientists were arguing against what they called the religious propaganda produced by scientists in Western Europe, especially in England. Eddington, Milne, Jeans, and other religious scientists were criticized, not only in the USSR but also by other scientists in the "West", for having introduced religious arguments into cosmological discussions, especially in popular books.
2. Summary: This phase includes discussion of the "tired light model", the origins of big bang cosmology, and the problem of the age of the universe, estimated as a few billion years in the Friedman-Lemaître models (and including a beginning point). This figure was lower than the estimated age of the Earth at the time, which provided a major challenge for cosmologists until the 1950s.

DESCRIPTION OF THE ACTIVITIES CONDUCTED IN HIGH SCHOOL PHYSICS CLASSES

The participating students, who came from three different public school classes, were quite impressed with the videos about various scales of the universe presented in the first activity. They debated cosmological questions in a spontaneous way in class, and, after that, were invited to write about the questions "The universe is so large, while we are so small. Do you think it is possible to understand the universe as whole? Is it worth studying?" on the course blog. Most of them valued cosmological research, but some believed that there are more practical matters that should be prioritized over such theoretical areas of research. In the second activity, another video captured the students' attention. The movie *Einstein and Eddington*, which showed debates about nationalism in World War I, and in which English scientists proposed a boycott against German scientists, was mentioned by several students in the following activities.

The Cosmic Game started in the third activity, with investigations simulating the period of 1914 to 1924. Initially, most groups wanted to explore the United States, Germany, or England, probably the most famous and rich countries, where they imagined science would be stronger. A few of them chose Russia, but few or no groups chose to investigate a neutral country. After reading and discussing the information they found, most groups argued either that the foundation should invest money in rich countries, because science and cosmology would have more of a chance to flourish in that context; or, on the contrary, that it should invest in poor countries, in order to help them with faster development. This shows a naturalized ideology that directly relates knowledge to economic development.

As expected, almost all student arguments at this point had little or no relation to science. Only after the teacher's explanations about cosmology, during the knowledge-organization activities, did cosmology contents appear in the debates.

It was also important to learn how to play the game, since the new "didactic contract" was very different from the traditional one. There were no right and wrong answers, and students had to learn how to organize useful information in order to create meaningful arguments. Student success was assessed not only by the teacher, but also by other students. In the second phase of the game, student arguments were much more complex and balanced, with a good mix of context and content.

In the fourth activity, as with the second, we noted that the plan for expository moments included too many different subjects; this led to classes with the teacher talking too much, and the students talking too little. We wanted to shape knowledge organization with a focus on the issues that were chosen by the students in the investigation, but noticed that it is not possible to talk comprehensively about such diverse topics as the role of women in science, relations between science and religion, the use of chemical weapons in the war, and the static cosmological models of Einstein and De Sitter in one session. Therefore, the issues discussed in every class were slightly different. In all of them, the debate between Einstein and Friedmann was emphasized, which led to interesting discussions about the system of peer review used for scientific articles, and possible influences on this process.

The fifth activity was the moment in which students could use what they had learned to choose one scientist to be awarded the "first round prize". As intended, following the classes that focused the debates on cosmological concepts, the ensuing arguments were much more complex and balanced, with a good mix of context and content. There was a balance between the number of groups that supported Einstein and the static universe, and the ones that were on Friedmann's side of the discussion.

Many of the Einstein fans had a comprehensible but naive admiration for the scientist chosen by *Time Magazine* as the most influential person of the 20th century. Knowing that Einstein had admitted his mistake as a referee of Friedmann's article, many of the students who supported the expansion of the universe valued the latter's critical attitude in challenging the authority of such a famous scientist. His inspiring role for young Russian scientists, in showing that common people might challenge ideas accepted even by powerful authorities, was celebrated by many students.

This led to an interesting debate in which one group voted for Einstein essentially because he had admitted he was wrong. According to them, "it is important to acknowledge an error because this helps him understand his own theory. Someone from outside helped him to view errors he had not seen". The rival group disagreed, saying that although it is indeed nice to admit your own errors, this was not a good enough reason to give the "prize" of the round to Einstein.

The prizes of the round were given to three different scientists in the three classes: Einstein, because most cosmological models discussed were based on his equations of general relativity; Eddington, because he had a good balance of theoretical and observational investigations, and was interested in testing cosmological models; and Friedmann, because he challenged the authority of a much more famous scientist (Einstein), inspiring young scientists in Russia. This shows that this game is very complex and rich, with different results every time it is played.

The second round of the game started with the sixth activity, in which students investigated the period from 1925 to 1931. In this round, Russia was visited by many more groups, since they had noticed Alexander Friedmann's importance. Despite the teachers' efforts to show the prominence of Willem De Sitter, once again almost no group investigated a neutral country, and Germany, the United States, and England were once more the most chosen countries.

The students naturally accepted the expansion of the universe, once they knew that it was posited by Lemaître and Eddington in 1931. Since Einstein himself changed his mind in this same year, accepting that his static model of the universe was obsolete, no groups doubted that the universe must be expanding. Some groups voted for the USA because of its large telescopes, while others voted for France and England because of the work of Lemaître and Eddington. There was a balance between arguments related to cosmological concepts and to the contextual aspects of science. The direct association between economic development and science appeared again, but comparatively less than in the first round. One group voted for investment in the USSR because it was not affected by the crisis of 1929, while another group voted for England for the opposite reason: because it had been so greatly affected by the crisis.

The second activity in the second round, in which the knowledge that emerged from the investigations about the period from 1924 to 1931 was organized, focused on debates about the acceptance of the expansion of the universe and priority disputes regarding works by Lemaître in 1927 and Hubble in 1929.

The seventh and eighth activities were part of the moment of organization of knowledge that emerged from the investigations in the second round. Initially, students analyzed graphs of redshift plotted against distance produced by Silberstein, Lundmark, and Hubble, noticing that Hubble was not the only astronomer who investigated the redshift-distance relation. Later, they debated priority disputes about who should be credited with the "discovery" of the expansion of the universe. Like historians of science, the groups of students were divided: some argued that Hubble deserved credit for having presented more accurate measurements of distances of nebulae, leading to a trustworthy linear redshift-distance relation, while others argued that Lemaître deserved the credit, having argued explicitly and before Hubble that the universe is in expansion.

This polarization was important for the debates in the ninth activity, in which the groups had to choose the "second round prize". For this activity, many students prepared studies at home, bringing extra research material obtained from Internet websites and other non-trustworthy historical sources to the classroom. This influenced many groups to vote for Hubble: all groups chose him in one of the classes, which led us to ask them to debate who should be awarded the "second prize". This was considered quite unfair by some groups, which had prepared lots of arguments for Hubble, but had few for the other scientists.

Many of the arguments taken from the Internet were historically inaccurate: groups voted for Hubble because he "discovered the expansion of the universe", or because his "redshift observations proved that the universe is expanding". The teacher problematized these arguments, noting that in the previous activities it had been discussed that Hubble had not even believed in the expansion of the universe, and was by no means its only "discoverer", since several other scientists investigated this topic. The creation of the relativistic expanding model of the universe was a collective process, extended in time, by several different authors.

After Hubble, the scientists that were chosen most often for the prize were Lemaître and Eddington.

Since many of the investigation cards presented debates about expansion together, many groups voted for one or another scientist with a similar argument: they deserve the prize for their contributions to the acceptance of the expansion of the universe. The debate shifted to a polarization between groups that valued Hubble's astronomical observations versus the ones that valued Friedmann, Lemaître, and Eddington's theoretical work on expanding relativistic models.

STUDENTS' CONCEPTIONS ABOUT SCIENCE

Throughout the activities of the didactic sequence, we analyzed students' conceptions about science. We recorded and transcribed the oral debates that were part of the game and read the texts produced by students in classes and posted on the course blogs.

Most of them agreed that "cosmology is a reliable and neutral way to know 'who we are' and whether the universe had a beginning or has always existed". As expected by the researchers regarding typical student conceptions of science in the last decades, we confirmed that the naïve "empiricist" and "inductivist" views of science were the most common perspectives among the high school students studied. Most of them trusted science much more than other ways of thinking about the origin of the universe, and few religious students stated explicitly that they trust their religion over scientific cosmology. We found almost no examples of relativist students in this initial investigation.

We started problematizing these naive views about science, debating some cultural and political influences on science during World War I, like the boycott of "German science" and the theory of relativity by some allied scientists. The result was that most students retained their defense of the neutrality and universality of science as a value or aim of science, but acknowledged that sometimes scientists might act in ways that disregard these values.

We also noted at this juncture that a small number of students expressed certain radical relativist views. One student stated that science is not neutral because: "each country has its theory, its party, its opinion". With a radical association of scientific knowledge and power, she argued that "if you have a different theory it might cause a war against the opponent. If some country is at war against another country and this country is stronger, this will give it power over the weaker one". Thereafter, during all the activities, the teacher introduced arguments to criticize this kind of view. He emphasized that almost all discussions between scientists about cosmology were not personal, but based on theoretical and empirical arguments.

In the final discussions of the first round, the most prominent debate was between the supporters of Einstein and the supporters of Friedmann. We noted that many Einstein "fans" had very naive views of science: "Einstein was so intelligent and no one doubted him. He never needed any help to become who he was". This kind of myth helps to propagate misconceptions about science, like the idea that the "greatest geniuses" of science make discoveries alone, do not make mistakes, and should not be questioned.

On the other side of the debate, several Friedmann supporters valued exactly the opposite: the fact that the young, unknown Russian scientist had challenged the authority of Einstein, who was already quite famous and, at the time, had just won the Nobel Prize. This shows that critical enquiry, enquiry that does not submit to power or other political and cultural influences, was important for many students. Their view of science was much closer to the Mertonian "ethos" of science than to postmodern relativism.

These students, who were actively engaged in game debates, showed a more mature and rich perspective on science. They did not see scientists as infallible geniuses and saw errors as a natural part of the process of the creation and validation of theories.

In the second phase of the game, debate about the Einstein's "errors" appeared again, because, in 1927, Einstein repeated his position about Friedmann's universe: it would be mathematically correct but physically unimportant.

Most of the groups accepted the expansion of the universe at this point, and the number of Einstein supporters was shrinking. One student, who had not participated in the previous classes, voted for Einstein, arguing that "he was the greatest scientist of all time and created the theory of relativity. Nothing compares to him". This led to heavy and loud criticism from all of the other groups, using Einstein's rejection of Friedmann and Lemaître's models as arguments against him. This time, the claim that "everybody makes mistakes sometimes" was not enough to save Einstein, who turned into a minor candidate for the prize in the second round.

Finally, in the last debate of the second round, one of the main objectives was to show that even though most books and websites about cosmology claim that Hubble "discovered the expansion of the universe", Hubble had in fact gone to his grave without entirely accepting this expansion. Instead, he supported a cautious interpretation of the cosmological implications of the redshift-distance relation until he died. Students also studied the contributions of other astronomers (like De Sitter, Silberstein, and Lundmark) to the establishment of the redshift-distance relation.

One very nice surprise was that many students decided of their own volition to prepare themselves for the last debates, which shows that they were highly engaged in the game. However, as we did not expect this, we had given no orientation as to appropriate, reliable research materials that could be used to study the history of cosmology, since we believed that the material provided on the course blog and the cards used in the investigations during the game would be enough. However, students themselves decided to search for other resources, especially on the Internet.

This led us to realize, as might be expected from the results of former research about conceptions of the nature of science, how difficult it is to change students' naive ideas about science. Despite all of our efforts, many groups used their Internet research to argue that "Hubble proved the expansion of the universe".

The teacher problematized these arguments once more, accommodating for the more historically adequate claim that Hubble's measurements of nebular distances allowed, with time, the astronomical community as a whole to arrive at an interpretation of redshifts supporting the relativistic models of a universe in expansion.

FINAL REMARKS

We have produced a didactic game about cosmology that was used to stimulate discussions about controversial science issues in high school physics classes. Since most proposals for introducing the history of science in high schools are based on reading and discussing texts, this game might be a good way to diversify the kinds of didactic strategies used in such science teaching.

The game involves both regional aspects and a process of historical evolution, in which each round simulates a time period. In their investigation of the history of science in each country and in each historical period, students who play the game read about not only scientific concepts, but also about politics, culture, and arts. This approach ideally leads players to notice the interrelations between scientific activity and these extrinsic influences, thereby learning that science is influenced but not determined by its sociocultural context.

The study of historical episodes was important for showing students that theories change with time, that scientists make mistakes, and for avoiding the notions that scientific theories are absolute truths and scientists are purely rational and neutral human beings, isolated from personal and social influences. On the other hand, it was also important for students to understand the arguments that led scientists to change their views about cosmological models in each period, to realize that those debates were not personal, but based on astronomical observations and their interpretation via physics theories. In this way, the game can help teachers to problematize the simplistic perspectives – whether absolutist or relativist – of their students.

The debates undertaken throughout the game proved very productive for analysis of the students' conceptions of science. We noted that discussions between students, as supplemented by the interventions of the teacher during the game, were effective in problematizing certain naive views about science, such as the belief that great geniuses like Einstein are never wrong, or that they make all of their important discoveries alone, isolated from sociocultural issues and the contributions of other scientists.

It was also interesting to note that many students were engaged in the game to such an extent that they decided to search on their own for extra Internet sources on the history of cosmology. This led many students to bring historically-inaccurate arguments to the debates, which showed us the importance of introducing guidelines for reliable historical sources in case students want to prepare for the debates on their own when playing this game.

The interesting debates undertaken by the players of this game lead us to conclude that it might be developed into an effective and enjoyable didactic strategy for the study of other historical episodes and issues about the nature science.

NOTES

1 Acronym from the Portuguese name for the Theory and History of School and Scientific Knowledge group.

[2] The Rockefeller Foundation (http://www.rockefellerfoundation.org/our-focus) is a philanthropic organization. Its central mission over the past 100 years has been "to promote the well-being of humanity throughout the world". This includes the development of science. Though the foundation in our game was based on the real Rockefeller Foundation, it is important to stress that there was never a subdivision devoted to funding cosmological research. This was a fictional invention.

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Alexandre Bagdonas
Department of Exact Sciences
Federal University of Lavras (DEX UFLA)
Brazil

André Noronha
Federal Institute of São Paulo (IFSP)
São Paulo-SP, Brazil

Vitor Machado
Dona Ana Rosa de Araújo Public High School
São Paulo-SP, Brazil

Felipe Velásquez
University of São Paulo
São Paulo-SP, Brazil

Ivã Gurgel
Department of Experimental Physics, Institute of Physics
University of São Paulo
São Paulo-SP, Brazil

THAÍS CYRINO DE MELLO FORATO AND
ALEXANDRE BAGDONAS

11. A PROPOSAL FOR OVERCOMING OBSTACLES TO TEACHING NATURAL SCIENCE

Evaluating a History of High School Cosmology Courses

INTRODUCTION

For some decades, reflections on science and its relations with other fields of knowledge have been encouraged among different areas and levels of education where such approaches to the history of science have been considered efficient methodological resources (Abd-El-Khalick, 2012; Hodson, 2014; Pietrocola, 2003). However, how may we appropriately bring such specialized interdisciplinary knowledge to high schools? Is it possible to harmoniously integrate scientific, epistemic, and non-epistemic contents within the current historiographical perspective without incurring distortions (Allchin, 2006; Forato, 2009)?

Many such questions may be theoretically and methodologically grounded in research into the history, philosophy, and sociology of science in science education, a line of inquiry which has grown substantially over the last decades and offers possibilities for approaching the epistemology of science by means of its history (Zanetic, 1989; Martins, 1990; Matthews, 1992; Arduriz-Bravo & Izquierdo-Aymerich, 2009; Forato et al., 2012a; Bagdonas & Silva, 2015; Dagher & Erduran, 2016). This research allows us to understand fluctuations in scientific objectives and the impermanence of some scientific theories, as well as articulating scientific content vis-à-vis cultural contexts and social uses (Porto, 2010; Rudge & Rowe, 2009; Zanetic, 2006). In fact, comprehending these and other aspects of the nature of science (NOS) is considered an essential component of scientific literacy today (Lederman, 2007).

Understanding the development of science as a social and historical product enables us to reflect on the scientific enterprise and its limitations, an important aspect of science education. However, several challenges must be faced in order to effectively develop and implement historical approaches for the classroom, whether in high schools or in university education. The literature has been pointing out issues which range from teachers having difficulties in understanding historiographical assumptions and historians of science having difficulties in understanding the prerogatives of science didactics (Holton, 2003); to the naive or mistaken perspectives nourished by didactic materials (Allchin, 2006); the lack of appropriate materials and methodologies for the classroom (Forato et al., 2015;

M. Pietrocola & I. Gurgel (Eds.), Crossing the Border of the Traditional Science Curriculum, 181–205.

Martins, 2007); the shortage of properly trained teachers (Gil Perez et al., 2001); and conflicts with school contexts in initial teacher training (Höttecke & Silva, 2010), among others.

It is also necessary to understand that each historical episode may explain only certain aspects of the NOS (Martins, 2006). When the NOS is taught based on the study of a given historical episode, there is a risk of generalizing what has been learned from that specific episode into science as a whole. For example, when teaching about the relationship between observation and theory by investigating empirical inductivism in the history of optics in Ancient Greece and in the context of the 17th century (Forato, 2009), or when discussing the history of cosmology in the 20th century (Bagdonas, 2011, 2015), we can't presume that the different epistemological aspects evident in these episodes would be found in all sciences in all historical periods.

Some writers have advocated that we ought to be careful when teaching about the NOS, to avoid providing students with an essentialist notion of science, according to which all different scientific subjects may be equally described by a set of fixed lists which do not evolve with time (Eflin et al., 1999; Irzik & Nola, 2011; Allchin, 2011; Bagdonas et al., 2015a).

Within this range of hardships, this project focused on the challenges and obstacles encountered in the development of didactic proposals for high schools, through the selection of historical episodes and the construction of pedagogical materials and didactic activities.

As a result, we are able in the following to address different obstacles to the didactization of the history and epistemology of science, by giving examples of the use of methodological supports helpful in offsetting challenges. First, we present a brief synthesis of our research, which analyzed the challenges, dilemmas, and obstacles at the confluence of historiographical and didactic requisites, during the construction and implementation of a history of optics course for high schools (Forato, 2009). This analysis lead to the proposal of parameters that aim to assist in confronting obstacles to the development of historical approaches as a pedagogical strategy for education. The reflections demanded by the parameters provide support for seeking consistency between the intended view of science and the aspects of the NOS which may be debated in each historical episode narrative (Forato et al., 2012a). The core of our proposal involved efforts to avoid contradictory views on the NOS.

In the second part of this chapter, we seek to provide an example of how such parameters may be used to analyze and/or develop didactic proposals for the school environment. We then present the application of these parameters in our analysis of a didactic sequence for high schools on the history of cosmology, focusing on the period of the first decades of the 20th century (Bagdonas, 2015).

Finally, we present some of the contributions and limitations of the parameters as far as overcoming obstacles and supporting decisions about pressing aspects of the uses of history of science and NOS education, as well as the possibilities for development provided by such analysis.

HISTORY AND EPISTEMOLOGY IN THE SCHOOL ENVIRONMENT: CHALLENGES AND DILEMMAS

When choosing to add aspects of the NOS to specific physics contents, it is necessary to assess whether the historical approach used is coherent with the notion of science one seeks to develop. Although debates about the losses for student education caused by whig, presentist, and linear historical narratives have been taking place for decades (e.g. Kuhn, 1997 [1961]; Brush, 1974; Whittaker, 1979; Allchin, 2004), it is still possible to identify naive conceptions of the sciences conveyed by the historical narratives currently in use (Gil Perez et al., 2001; Hodson, 2014).

In general, such usage occurs due to a lack of familiarity with historical methodology and historiographical assumptions, both of which forms of knowledge are intrinsic to the training of historians (Holton, 2003). On the other hand, how can a historian of science, unfamiliar with the didactic prerogatives of science and the classroom, develop approaches which are appropriate to the school environment and which effectively favor students' learning and participation?

Aiming to deal with this challenge, a case study involving the history of optics has been developed (Forato, 2009) by considering the requisites of the historiography of the history of science (e.g. Gravoglu, 2008; Jardine, 2003; Martins, 2010; Kragh, 1987) and recognizing the different social and formative roles of the knowledge produced by specialists and the knowledge effectively proposed for high schools (Chevallard, 1991).

This research analyzed the construction and implementation of the course, identifying the challenges, strains, and obstacles at three levels of investigation: (i) theoretical analysis, (ii) empirical analysis during the construction of the course, and, (iii) the comparison of those results with data obtained in the classroom. After the global assessment of these three stages, twenty parameters were proposed for addressing obstacles in the didactic transposition of the history of science to the school environment (Forato, 2009; Forato et al., 2012a). These parameters are intended to assist in the development of didactic materials and proposals using the history of science as a didactical resource. We present a synthesis of these stages in Table 1, which will be discussed in the next sections.

Theoretical Analysis Comparing Historiographical and Didactic Requisites

During the theoretical analysis stage, a comparison between the assumptions of contemporary historiography and the needs of the classroom allowed us to anticipate eight challenges/obstacles in the didactization of historical episodes. In addition to this, four dilemmas or strains were also anticipated, which led to inevitable risks due to the simplification and omission of historical contents (Table 2). We present below a synthesis of the result of that analysis.

Table 1. Stages of research on the history of optics and results obtained. (Source: Forato, 2009)

Stages of research	Results obtained
Theoretical analysis comparing historiographical and didactic requisites	– 8 challenges, obstacles – 4 dilemmas, strains, risks
Empirical analysis during the construction of didactic materials and activities	– 9 surmountable obstacles – 8 avoidable obstacles
Comparison of theoretical and empirical analysis with classroom results	– 20 parameters

Table 2. Challenges and dilemmas identified during theoretical analysis. (Source: Forato, 2009)

Challenges and obstacles	Dilemmas, strains, and risks:
I. Selection of historical content II. Didactic time available III. Simplification and omission IV. The risk of Relativism V. The inappropriateness of specialized works VI. Pseudohistory in the school environment VII. The alleged "benefits" of linear reconstructions VIII. Teacher training	1. Extent *versus* depth 2. Comprehensibility *versus* historical accuracy 3. Simplification or distortion 4. Objectivism *versus* subjectivism

The first challenge is the *selection of historical content* (I), which is guided by the intended *scientific-educational purpose* and by the *epistemological aspects* that should be designed to *engage* students (Freire, 1996). Furthermore, this selection must satisfy the requirements of the *formal educational context* (e.g. level of education, adopted curriculum, hours), and consider the particular *social and cultural context* and *conceptual prerequisites* concerned. It is neither obvious nor simple to attend to these six requisites.

Developing the proposed content within the *didactic time available* (II) is the second challenge. This assessment is not limited to the number of hours available, but considers the interdisciplinary characteristics of the history of science and the time necessary to learn complex contents, such as those regarding various historical, epistemological, and sociological aspects of science, in addition to physics concepts. One should take into account the fact that teachers of the natural sciences face challenges in dealing with this new knowledge, which is ontologically and epistemologically distinct from their area of education. Therefore, *didactic time* varies according to educational context and the concept encompasses a much wider span than the simple calculation of the period of time the teacher has available. It influences the challenges of the *selection of historical content* directly, requiring a deep and detailed analysis, as it will be further discussed below.

The third challenge, *simplification and omission* (III), involves establishing the level of depth to be included in the selected historical content. Using the intended epistemological objectives as an indicator, it is necessary to choose which aspects of the historic episode to omit. This is as important as selecting the items to be addressed, since there is no neutral or complete historical narrative:

> From historical chaos, the historian creates an understandable order, by means of a process, which *selects* what is described and according to the *connections* he/she makes up. Even if his/her selection does not lead to a linear history, countless aspects have been omitted and a great simplification of historical intricacies has occurred. (Martins, 2010, p. 6)

It is not a trivial matter to assess the details which may be simplified or which could be omitted without compromising the quality of the historical narrative. Any choice is affected by implied values that may impact intended objectives. Excessively superficial accounts may twist the understanding of the NOS (Forato et al., 2015). Reconciling scientific concepts, elements of historical context, and epistemological aspects in a limited *didactic time* is much more than mere simplification.

The risk of incurring *extreme relativism* (IV) is the fourth challenge. When one seeks to interrogate the exclusively empirical-inductivist perspective of science generally maintained by science education, the limits of observation of scientific research are presented, thereby producing the risk of suggesting or encouraging the notion of a complete lack of objective parameters. Criticizing naive empiricism, via questioning the exclusive objectivity of science, may lead the student to believe, for instance, that the different existing theories which try to explain the same single phenomenon are simply personal opinions. The manner in which historical content is presented should allow debates about the neutral observation of phenomena and experiments, without, however, devaluing the importance of observation, of experimental evidence, of rational arguments, and of skepticism in the construction of scientific knowledge.

Although consistent with current historiography, *the inappropriateness of specialized works* (V) is another challenge. Even if a teacher is able to find a text written by a historian of science which satisfies his/her educational purposes, how might s/he use it in the high school environment? Besides not being written for high school students, the conceptual prerequisites of the fields involved and the depth of historical pieces make such works inappropriate and even boring for students. Excerpts from primary sources may provide valuable contributions to education only if they are duly contextualized, as the methodology of analyzing historical documents is complex and reading them anachronically always bears significant risks.

Another challenge (VI) is dealing with *pseudohistory in the school environment* as found in the naive narratives of history present in textbooks. These are configured as pseudohistories (Allchin, 2004), with all the problems arising from such a profound misconception. The standard perspective of the history of science, which has been maintained both implicitly and explicitly in science education, is exactly that outdated perspective, and is supported by such still-present approaches.

This perspective is reinforced by another challenge, the widespread belief in *the alleged benefits of linear reconstructions* (VII). Even if there are good arguments about the envisioned pedagogical benefits of a linear view of history, which validate the currently-accepted concepts,[1] the losses caused by such versions of history cannot be denied.

The lack of *teacher training* (VIII) is one of the greatest challenges to be faced. All of the above obstacles would be mitigated by teachers trained to deal with such obstacles in a critical and sensible manner. We deem it neither possible nor necessary to transform teachers into historians or epistemologists of science, but it is essential to develop activities that provide elements that help teachers to cope with the challenges of the uses of history and philosophy of science in the school environment.

The didactization of the history of science implies difficult choices and dilemmas; in some cases, any option implies inevitable losses. Will establishing a historical framework allow a high school student to understand the role of a certain "isolated" historical event in the construction of science? Or even to understand it as only one perspective, among several, on events that took place in the past, and which are related to a complex variety of cultural factors? Is it possible to present a specific account of an historical occurrence without the student losing a broader perspective of that event in history?

Deciding between a specific frame and a broader temporal approach, that is, choosing between *extent versus depth* may become a source of conflict. Again, the decision between these approaches ends up depending on the context of the use of history and the intended pedagogical goals.

Another conflict which is difficult to resolve and may result in didactic dilemmas emerges in the process of going deeper into a chosen historical episode: what, exactly, are the *aspects to be omitted*? In this case, it is also necessary to analyze the context of each situation; for instance, a given episode may include aspects favorable for addressing a certain aspect of the NOS, but may require an overly-extensive approach for a certain classroom context. The intended pedagogical objectives, the level of education involved, the conceptual prerequisites necessary for student and teacher, as well as approaches that relate to specialized aspects of the history of science, are all factors in the latter. In which situation should a certain social, historical, or scientific aspect be deemed "unnecessary" given the pedagogical objectives pursued? In which situation does a specialized detail become essential for the comprehension of an intended objective?[2]

This may be seen in choices that involve mathematics. Many episodes require mathematical knowledge at a level inaccessible to high school students. On the other hand, should the *omission of mathematics* when addressing a concept, experiment, or theory be considered *simplification or distortion*?

Another conflict is related to the *text* of the historical narrative, not only regarding colloquial or scholarly language, but the level of details, connections between ideas, complexity of information, and reflections. If we opt for an overly-simplified historical text, we run the risk of incurring pseudohistory. On the other hand, an account that is deeply committed to historical accuracy may be incomprehensible to students. Finding the middle way requires persistence, a large dose of creativity and, at times, the flexibility to give in to one side or the other. In this process, we encounter *comprehensibility versus historical accuracy.*

Questioning the exclusively empirical-inductivist perspective of science, by discussing chosen aspects of the history of science, implies potential risks. Criticizing that perspective may convey a misleading *devaluation of the role of experimentation* in science. In addition, in considering such matters as the historical construction of science, theories which cannot be proven, and the existence of competing explanatory models for many natural phenomena, as well as the problems and limitations in long-accepted theories, one may suggest or even encourage *subjectivism*, which may lead to a naive relativist or social determinism of science perspective on the parts of students. Therefore, we have the conflict/dilemma of *objectivism versus subjectivism*.

A theoretical analysis which confronts historiographic and didactic requisites may point to paths for dealing with challenges in terms of structural obstacles, conflicts, and dilemmas. In addition, one can gain from practical experience in facing these difficulties in the process of teaching and learning. Thus, an empirical analysis was carried out to complement our theoretical approach to confronting obstacles, in the development and implementation of a pilot course for senior high school. The empirical part included the preparation, application follow-up, and analysis of a series of didactic activities which use the history of optics to discuss the NOS aspects of the construction of scientific knowledge. Scientific and formative aspects were also integrated.

OBSTACLES FACED IN THE CONSTRUCTION OF A HISTORY OF OPTICS COURSE

Bearing in mind the results of the above theoretical analysis, a 20-hour mini-course on the history of optics was developed for senior high school, in the context of a public school in the suburbs of the city of São Paulo. The analysis of this empirical process, the experience of further challenges, and the solutions proposed for the obstacles faced, created another set of results.

During the selection of historical episodes, the elaboration of the texts written for the teacher and for the students, and the construction of educational activities, the eight challenges and four dilemmas which we had expected in theory did in fact arise.

In addition to this, new obstacles unfolded along with the expected challenges during the empirical process of course planning, providing more details of the difficulties which may be encountered in teaching the history and philosophy of science (HPS). This new set of results resulted in 17 obstacles inherent to specific educational contexts. Table 3 presents a synthesis of those obstacles, and distinguishes between those that are surmountable and those that may actually be avoided.

Table 3. Surmountable and avoidable obstacles identified during the empirical analysis. (Source: Forato, 2009)

Surmountable obstacles (SO)	Avoidable obstacles (AO)
1. Notion of science to be presented: selection of the aspects of NOS. 2. Selection of the historical aspects to emphasize in each episode. 3. Level of depth of certain historical aspects. 4. Level of details of non-scientific context. 5. Level of depth of certain epistemological aspects. 6. If, when, how much, and how to use excerpts from primary sources. 7. Creation of a discourse that is appropriate to the intended level of education. 8. Addressing, diachronically, (a) different notions of science; and (b) thinkers of different eras; and (c) contents of the history of science which are hard for contemporary students to understand. 9. Construction of educational activities which are appropriate from pedagogical and epistemological points of view.	1. Naive notions of the history and epistemology of science. 2. Teacher's lack of preparation. 3. Inadequacy of specialized history of science texts of for high school. 4. Lack of student prerequisites in respect to mathematical, physics, historical, epistemological, and philosophical knowledge. 5. Possible preconceptions of teachers and students, overvaluing the capacity of current science to solve all problems. 6. Emphasizing scientific aspects or emphasizing factors which are external to science. 7. Amount of information in the form of texts. 8. Extent x depth.

In the educational context for which the course was developed, it was possible to propose solutions for nine of the obstacles; we have called these *Surmountable Obstacles*. On the other hand, it was not possible to overcome the other eight obstacles; in the latter cases, it was necessary to develop remedial strategies. Consequently, these were designated as *Avoidable Obstacles*.[3]

Data obtained in the classroom demonstrates that the results of our proposed strategies exceeded expectations, both regarding students' capacity to learn about the NOS and their motivation and significant change in their engagement with physics contents presented during and after the course. Moreover, the teacher, who we trained and who taught the course, reported being happy with both her own learning and her accomplishments with the students (Forato et al., 2008).

It was possible to identify limitations too. Some of the conflicts or dilemmas predicted in the theoretical analyses manifested following the use in our history of optics course of a short narrative of Thomas Young's contribution to the wave theory of light. The absence of some historical information or its excessive simplification promoted a naive view concerning scientific endeavor. Of course, in most educational settings it is impossible to present a truly detailed historical account of scientific episodes (Forato et al., 2015).

In light of this set of results, some questions arise: to what extent could the proposed solutions be generalized? Could our results contribute to the construction of other educational proposals? Would it be possible to organize the analysis of all these difficulties and the proposed solutions so as to provide a base for the didactization of the history of science? The next section explores the results of the entire project, and seeks to clarify the prepared proposal.

PROPOSAL FOR COPING WITH OBSTACLES

The history of optics course was implemented in the last year of senior high school. The collection and analysis of data was based on qualitative research, which configures a case study, in a specific context, with the researcher immersed in the natural environment in which the educational event takes place (Bogdan & Biklen, 2004; Ericson, 1998). For the triangulation of data, three different sources were used: the transcripts of the classes as recorded on video; the answers provided by the students during activities and in their final evaluations, as well as the researcher's field notes (Carvalho, 2006). The analysis focused on the process of relations between the students and teacher and the HPS contents, looking at progressive changes in their views on aspects of the NOS. It consisted of comparing classroom dialogs with the epistemological objectives of the proposal, and with the students' written material, as well as the teacher's lectures (Forato, 2009). The purpose was to evaluate which reflections, information, discussions, and educational activities contributed more effectively to student learning. In addition, we sought to determine which piece(s) of information, if any, might result in an undesired interpretation.

By carrying out a global analysis of results, considering the challenges and obstacles identified in the theoretical and empirical analyses, the educational proposals for overcoming them, and the classroom results, we sought to identify specific aspects of the construction of the course which were conducive to good results, as well as limitations that would need improvement. As a general result of that research process, 20 parameters, which are intended to assist in the didactization of historical and epistemological content, were prepared.

Such parameters are neither rules nor a recipe for developing didactic material, on the contrary, they include details that should be reviewed and reconsidered during the whole process of development of any pedagogical proposal. They require analysis and reflection as to the questions raised and challenges recalled, based on the purpose established for each educational context.[4] The parameters will appear in italic in the next sections, as items for guiding reflections.

Our starting point is an analysis of the consistency between the intended pedagogical and epistemological objectives, and the historical narrative, which is adopted or constructed by constantly evaluating the selection, omission, emphasis on, and simplification of historical contents. Although an evaluation of the correspondence between what is sought and what is obtained may seem obvious, countless researchers attest to the tenacity of naive perspectives of historiography in science education (Abd-El-Khalick, 2012).

Our parameters further suggest some elements to be considered in the creation of didactic activities employing the mobilization of one epistemological objective in different historical examples and different pedagogical strategies.

The next section presents an example of the application of these parameters in the analysis of a history of cosmology course.

USING THE PARAMETERS: THE HISTORY OF COSMOLOGY IN HIGH SCHOOLS

In order to explain how the parameters may be employed in the construction and evaluation of educational proposals, we are going to present their application in the analysis of a didactic sequence on the history of cosmology developed for high school physics classes. This sequence was collectively elaborated by several members of the TeHCO (Theory and History of School and Scientific Knowledge) research group, at the Institute of Physics of the University of São Paulo. It was first developed in May of 2012 and was taught at the Escola Estadual Ana Rosa (Ana Rosa State School), in São Paulo, between April and June of 2013, as part of a doctoral research project on science education (Bagdonas, 2015). Data collection and analysis were done following a qualitative research methodology.

Initially, the group's proposal was to seek, in the study of episodes from the history of cosmology (Kragh, 1996; Bagdonas, 2011), aspects which would encourage discussions about controversial aspects of the NOS, especially those involving the complex relationships between science and its social and historical contexts (Bagdonas et al., 2015b).

As a way to find alternative strategies for teaching the history of science and to avoid the creation of a sequence based only on reading, discussing, and interpreting texts, the group decided to create a didactic game, which is described in detail in chapter 10 of this book. In summary, teachers and students play roles as members of an institution which supports research on cosmology. Students do research about the history of science between 1914 and 1939 in order to formulate arguments about which countries and scientists deserve to have funding. That research was performed in the classroom, based on reading, and on group discussions of the cards prepared by the research group. In addition to this,[5] between classes, students were able to conduct additional research on the course blog,[6] which included all cards from previous classes. We expected students to learn to understand history, as well as the history of science, as human constructions, taking into account that there are a variety of social and political influences on historians' interpretations of historical documents. For that reason, the teacher always highlighted that the information included in the cards was not intended as ready-made arguments; in order to formulate an argument, it was necessary to interpret the information. Students learned that several factors, such as our beliefs, points of view, and ideologies, may influence these interpretations.

One of the main challenges during the collective construction of the didactic sequence and of the game was to meet both the recommendations of researchers interested in history and philosophy of science education, and the didactic necessities of the classroom, which in the group were mainly represented by the experience and views of the high school teachers. The group avoided consensus and valued disputes, both of a scientific nature (as in disagreements among supporters of different theories), and regarding the NOS (Bagdonas et al., 2015; Noronha & Gurgel, 2015), especially as involving tensions between rationalist and relativist perspectives on science, and the impact of social, cultural, and political influences on scientific development. For this reason, the fact that the parameters (Forato, 2009) deal with possible frictions between historiographical and educational requisites proved appropriate for enriching our discussions. The parameters were discussed at length in one of the meetings of the research group in September of 2012; this conversation guided the further systematization of the proposal that had been under discussion since May of that year.

At that time, some doubts about the use of the parameters remained, but the sequence was completed and implemented in the classroom in 2013. Later, in 2015, after a defense was completed of the dissertation analyzing this didactic intervention (Bagdonas, 2015), the authors of this chapter continued their reflections about the use of the parameters in this course. This further analysis made explicit the aspects of the NOS that had not been clear previously; and pointed out elements that might be improved in future iterations.

We present below the results of these new reflections about each parameter. For now, this is the final version of our discussions, for, as mentioned in the previous section, it is necessary to once again reflect on a given project when we identify an inconsistent or incomplete aspect, or when any details under consideration point to new developments.

1. *Establishing pedagogical purposes for the uses of the history of science in education:*

The general purpose of the sequence is to allow students to gain a richer understanding about the ways science relates to its social and historical context.

We developed a series of specific objectives in order to meet this goal:

A) Learning scientific concepts, such as:
- Cosmological constants and the static universe;
- The expansion of the universe and redshift; the relation between spectrum shift and distance (known as the Hubble law); and the different interpretations of redshift.

B) Learning aspects of the NOS, such as:

- Questioning the neutral nature of science and empirical-inductivist perspectives;
- Questioning social determinism and naive relativism;
- Methodological pluralism: learning about some of the different methods employed by scientists;
- Discussing the concept of priority disputes in scientific discovery;
- Realizing that the same experimental data may be analyzed from different theoretical perspectives.

C) Supporting the development of skills, and procedural and attitudinal contents, such as:

- The reading and interpreting of texts, graphs, and tables;
- Arguing for a point of view with clarity, listening to opposite positions, and debating scientific topics.
- Working in groups, thus contributing not only to ones' own learning, but also to collective learning.

2. *Explaining the notion of science adopted and/or the intended epistemological or metascientific goals*:

The main epistemological objectives are questioning both naive rationalism, the idea of a neutral scientist, free from ideological influences; and naive relativism, the idea of a scientist whose personal opinion guides his/her conclusions or who is dominated by ideological influences. We expect students to see science as a human construction influenced, but not determined, by social and historical context.

Cosmology is a branch of science which may be especially suited for allowing certain aspects of the NOS to be discussed in more detail. In the first half of the 20th century, religious, ideological, aesthetic, and political issues notably influenced cosmological debates (Bagdonas, 2011, 2015; Kragh, 1996). These clear and strong influences were a good reason to choose this scientific field during this historical period as a launching pad for discussions about the influence of social and historical contexts on science.

Moreover, since it is not possible to perform lab experiments to test cosmological theories, studying cosmology provides useful ways to teach students that scientists employ a variety of different methods.[7] Astronomic observations, which allow us to draw inferences about the evolution of the universe, were even more limited in the first half of the 20th century, when the huge telescopes, satellites, radio telescopes, and other technological apparatus which have broadened our observational knowledge of the universe, had yet to be built. Even with this technological evolution, our knowledge is still very limited when compared to the immensity of the universe as a whole. It is interesting to note that this relative scarcity of observational data has not prevented the conception and development of several creative, rich, and interesting cosmological models.

The sequence also highlights reflections about the concept of "discoveries" in science, drawing attention to common media distortions of theory creation as a product of the mind of isolated "geniuses". Several "candidates" for the discovery of the expansion of the universe are presented, so as to allow students to understand that several different scientists contributed to the collective construction of those cosmological theories.

Finally, the sequence emphasizes disputes between rival theories, revealing the possibility of different scientists or groups positing different theoretical interpretations of the same observational data. This is an interesting strategy for questioning empirical-inductivist perspectives.

3. *Selecting the appropriate topic and historical contents:*

We selected the acceptance of the theory of the expanding universe between 1917 and 1939 as our central topic. As discussed in parameter 2, that subject is exceptionally appropriate for our discussion because, at that time, political and religious influences over science were particularly important.

4. *Selecting the aspects to emphasize and to omit in each history of science content:*

Aspects to emphasize

The historical episode comprises three stages, and each stage corresponds to a historical period that was explored in the game (see Chapter 9 of this book).

In the first stage, we emphasize the debate between the scientists Albert Einstein and Alexander Friedmann about the expansion of the universe, paying special attention to the system of peer review by exploring what occurred when Einstein was the reviewer of Friedmann's article in a German magazine.

In the second stage, we look into the contributions of Lemaître and Hubble to the theory of the expanding universe, debating who should be considered the "discoverer" of this theory. In this stage, we seek to emphasize that this theory is the product of a collective process.

Finally, in the third stage, we explore alternative theories for explaining the redshifts of galaxies, as a way to discuss different interpretations of the same observational data.

In addition to this, it is worth highlighting that during the process of debate during the game, several different aspects may be considered, depending on the interests of teacher and students. Game cards are not limited to aspects of cosmology, but may also include other theories of physics, and even political, social, and cultural aspects. For instance, in some groups, there were girls interested in female scientists, such as Emmy Noether. On the other hand, some boys were particularly interested in the contributions of science to the production of weapons during World War I. However, the structure of the game encourages students to be increasingly interested in topics related to conceptual aspects of cosmology (along with the many benefits to this choice outlined herein, this is also a subject less prone to gender divisions).

Aspects to omit

As the didactic sequence sought a balance between addressing cosmology content and its historical context, several conceptual aspects had to be omitted. For example, we omitted the mathematical formalism of relativistic cosmology, which involves differential equations or tensors, since such mathematical requisites would not be appropriate for high school students. We also did not address certain complex concepts, such as comoving distances, scale factor, and four-dimensional space-time, among others.

We also omitted deeper discussions about the differences between astronomy, astronautics, astrology, and other fields of knowledge which are sometimes confused with cosmology; more detailed explanations of certain astronomic concepts, such as methods for measuring the distance of galaxies, spectroscopy, absolute and apparent magnitude, and parallax; and in-depth explanations of the physics of spectrum shifts, the formation of spectrums, and the concepts of electromagnetism and quantum mechanics involved in their explanation. Even though all these concepts are important to a formal education in cosmology at the university level (since they are directly related to redshift), we speculated that it was possible to introduce an initial idea of cosmology while omitting these aspects in our high school educational context.

Moreover, according to the historical study frame already mentioned in parameter 3, the developments of post-1940 contemporary cosmology – including steady state theory, nuclear and particle physics, the origin of chemical elements, dark matter, dark energy, and inflation – were also omitted.

5. *Comparing the omitted aspects with the intended aspects of the NOS:*

The five aspects of the NOS listed in parameter 1, and described in parameter 2, were not impacted by the omissions. However, because we omitted several mathematical and conceptual aspects, there was a greater risk of overestimating political influences, thereby strengthening relativist perspectives or encouraging socially-deterministic views, as discussed in the second section of this chapter. We describe how to avoid this risk below, in parameters 6 and 7.

6. *Defining the level of detail of the non-scientific context to be addressed:*

As discussed in parameter 1, non-scientific contextualization is a part of the general purpose of the didactic sequence. The game was structured using geographical and historical divisions as a base, so that the historical, political, cultural, and economic knowledge of the period between the wars was an essential part of the intended learning.

Some aspects of the historical context were specifically highlighted, such as the impact of World War I on science, when, as nationalism intensified, along with disputes between rival countries, so grew the ideological influences on science in cosmological debates involving science, religion, and Marxism. This is demonstrated by the impact of the “primeval atom” theory conceived by Lemaître, a priest who proposed that the universe began some billions of years ago.

7. *Mediating simplifications and omissions, since emphasizing the influence of non-scientific aspects may generate extreme relativist interpretations:*

As a strategies to avoid students endorsing the simple social determinism of science, we emphasized cases during the debates in which two scientists from two different social contexts were able to obtain the same results (e.g., Friedmann, Lemaître, and Robertson); we attributed importance to mathematics (e.g., in discussions between Einstein and Friedmann); and to astronomical observations (e.g., observation of the redshifts of the Slipher nebulae, Hubble’s improvement of methods for measuring distance).

In analyzing the research data collected during the implementation of the didactic sequence, we observed that this strategy seemed to have succeeded, as we encountered few naive relativist perspectives during the course, even with the omission of the mathematical and conceptual aspects described in parameter 4. Most arguments put forward by the students demonstrated that they still value science, experimentation, rational arguments, questioning authority, and other typical “ethos of science” values (Merton, 1973). Even recognizing that scientists occasionally act against these values, most students considered such behavior a distortion of proper conduct, and something to be avoided (Bagdonas et al., 2015b).

8. *Assessing when it is possible to overcome or remedy the absence of prerequisites in mathematical, physics, historical, and epistemological knowledge:*

The absence of certain of the mathematical and physics prerequisites (such as knowledge of differential, integral, and tensor calculus, non-Euclidean geometry, electromagnetic waves, spectroscopy, the Doppler effect, etc.) required for an appropriate comprehension of relativistic cosmology was discussed in parameter 4. Many of these concepts were omitted, not only because they are overly complex for most high school students, but also because we decided to emphasize other aspects of our subject, such as discussions about the NOS. To supplement what was omitted, we used educational strategies and resources, such as animations, analogies, and comparison with qualitative aspects of the theories (presented in parameter 9).

We did not notice issues with a lack of historical prerequisites, as our high school students were rather familiar with the historical period in question (the students in our study had typically covered the 20th century during history classes in their last year of junior high school). However, students in general might benefit further from a cooperative approach involving both science and history teachers. As suggested and discussed in parameter 19, Forato (2009) has proposed a timeline which relates movies (a form of media easily accessible to students) to the historical context of the didactic sequence, while addressing other aspects of world history, such as World Wars I and II, the Russian Revolution, and the crash of 1929.

Regarding epistemological prerequisites, there are many important NOS concepts that were not directly addressed in the sequence, such as those of “law”, “model”, “theory”, “scientific method”, and “hypothesis”, among others. While we do not expect students to memorize the definition of such concepts, we do expect them to understand their meaning and use them accordingly; we remedied this situation by accepting a lax use of these terms, as we will discuss in parameter 9.

One historical and epistemological prerequisite, whose absence was unfortunately only noticed after classroom intervention, was the need for guidance in the selection of appropriate materials for research involving the NOS. Although our proprietary materials were carefully created to avoid distortions, we did not anticipate that, because they were so engaged in the game, students would be interested in doing their own research using other sources, such as websites. Since we gave no guidelines for such research, students ended up relying on a variety of inappropriate research resources regarding the history of science, such as websites containing misleading or erroneous statements (“Hubble proved the expansion of the universe in 1929 by means of observation”, and so on).

Another prerequisite for the sequence, which is simultaneously one of its didactic purposes, is the capacity to read and interpret texts, formulate arguments, and participate in oral debates. The further development of these skills is encouraged in the sequence since, even if students have trouble with these competences, we believe that it is part of the role of the physics teacher to support language and humanities teachers in overcoming student challenges in these areas.

9. *Combining a group of different educational strategies and resources may offset the lack of knowledge of certain physics and mathematical contents. When omitting mathematics/physics per se is not a problem for the intended objectives, other possible risks should be considered:*

In order to address a lack of physics and mathematical prerequisites, we adopted a qualitative approach, making it clear to the students that the course was not going to provide the sort of deep understanding of the subject which would only be possible through years of studying physics and mathematics at the university level.

Students studied the redshift-distance relation by reading excerpts of papers by Silberstein, Lundmark, and Hubble, and we created a computer animation to present Fritz Zwicky’s “tired light” theory. We also proposed analogies, including discussions about their limitations, such as using a balloon to represent the expansion of a 2-dimensional universe.[8]

The risks involved in this omission were discussed in parameter 7.

We identified another risk related to the proposed activity, the risk of an exaggerated competition between students who may be more interested in winning than in learning. For that reason, we sought to promote cooperation between everyone in the game, taking collective success into consideration in the assessment of the class. This kind of strategy implies another risk, since it requires class participation: if students are too lethargic and the teacher fails to motivate them, the sequence will not be successful.

10. *Defining the level of depth of epistemological content:*

As discussed in parameter 2, we seek to question extreme empiricist, inductivist, and relativist perspectives. The didactic game debates included different perspectives on the NOS, since students had to justify their choices by playing the roles of members of an institution which supports scientific research. These choices were extremely revealing – and we were able to identify, analyze, and discuss students' opinions of science vis-à-vis their choices.

Obviously, we did not expect students to have a deep understanding of epistemological concepts such as "neutrality" or "social determinism", as this game was probably one of the first incorporating studies about the NOS. The arguments formulated were considered appropriate even when students used terms such as "discovery", "evidence", "law", or "model" incorrectly, as discussed in parameter 8. Like Forato (2009, p. 185), we created texts adopting the standard rules of the Portuguese language, rather than strictly academic language, in an attempt to approximate students' everyday language. Activities were planned so as to use epistemological concepts without formally defining them, while constructing narratives and discussions which enabled the understanding thereof.

11. *Considering the use of primary sources in high schools:*

Certain sentences from articles written by scientists and excerpts from their letters were included in the creation of the materials and of the game. However, we also utilized lots of excerpts from secondary sources, as well as texts that had been adapted by members of the research group. All were used to facilitate student understanding and to avoid naive interpretations of historical documents.

12. *In the effort to diachronically address contents of the history of science which might be hard to understand in a contemporary context, one option is to establish a connection between the results relevant to the construction of science with discarded contents or with contents that might currently be deemed "strange":*

Since our sequence addresses relatively recent subjects, we assume that there is a smaller risk of failing because of anachronistic approaches, at least compared with learning about developments which are historically more distant, such as Aristotelian physics, or even the Copernican revolution. In the physics of the 20th century, many concepts considered correct by physicists are seen by non-experts as "strange": the theory of relativity disrupts intuitive notions of space and time; the big bang theory and its notion of the creation of the universe out of nowhere is in direct conflict with everyday expectations about the conservation of matter and energy. The alternative theories, which have fewer supporters, are also strange, as in the continuous creation of matter in steady state theory or the supposed loss of energy of photons in the "tired light" theory. Some students seemed to believe that theories from the beginning of the century were strange due to a lack of technological development. We tried to challenge this opinion by arguing that currently-accepted contemporary theories are equally strange and non-intuitive.

13. *In the effort to diachronically address different notions of science and the thoughts of the philosophers, natural philosophers, and scientists of different periods and civilizations, introducing students to contemporary thinkers working with the same methodological assumptions may help them to avoid criticism of the past for its prejudices and anachronisms:*

The selected historical frame was justified in parameter 3: we chose the period comprised between 1914 and 1939, favoring depth to the detriment of extent. For example, we explored the fact that one set of data indeed enabled different interpretations, but also made it clear that these interpretations depended on the scientific methodology accepted at the time, rather than being just a matter of personal opinion. This helped us to deal with the risk of extreme relativism, as well as to criticize the notion that purely objective and neutral observations occur, entirely free from theoretical influences, during the formulation of hypotheses.

Naturally, our didactic sequence would be more efficient if complemented by other sequences which approach the same or similar aspects of the NOS from other historical episodes such as, for example, the different creation myths of different civilizations in ancient times, the Copernican revolution (Reis et al., 2013), or contemporary cosmology after World War II (Arthury, 2010; Aguiar, 2010; Bagdonas, 2011).

14. *Introducing examples of refuted theories in different cultural contexts enables us to criticize naive ideas about the history and epistemology of science, as well as the idea that modern science may solve all of our problems:*

In our historical episode, we showed that general relativity prevailed over Newtonian gravity in situations when bodies were travelling at speeds comparable to the speed of light. Furthermore, we discussed how the once-new idea of a universe consisting of our Solar System was debunked by the theory of a much larger universe formed by billions of galaxies, thereby also replacing the heliocentric model, since this latter model revealed that the sun (a stationary body in the Copernican model) was in fact also moving. This was later augmented by the theory of the expanding universe, which was endorsed by the majority of scientists interested in cosmology, even though a few authors still argue that the universe is static. Even now, contemporary theories contain limited and unexplained elements, for example, the challenge of explaining dark matter and dark energy, which seem to comprise more than 95% of the observable universe.

15. *Advocating for new ideas incompatible with those prevailing in students' cultural knowledge bases requires the use of strategies capable of creating discomfort and conflicts that allow them to question pre-established ideas:*

As detailed in parameter 4, we seek to question the stereotype of Einstein as a neutral, impartial scientist supporter of internationalism. In introducing the context of the 1920s, we first presented Friedmann and Lemaître as unknown people with "weird" ideas; we then revealed that they later ended up questioning Einstein's authority and showing he was wrong in certain matters.

Another mindset that is difficult to change is the naive perspective on the NOS, which includes such notions as the idea that scientific theories may be categorically and finally proven by means of experiments. For that reason, we always try to emphasize the possibility of different interpretations of experimental data, especially of the spectral shift of galaxies.

16. *Offsetting the potential lack of teacher preparation vis-à-vis knowledge of history and philosophy of science for the classroom includes preparing him/her to identify and question anachronistic manifestations. Educational materials could include instructions and warnings about unexpected ideas and offer possible ways to deal with such issues:*

Students encountered and expressed historical distortions, which were questioned during the sequence. They learned, for example, that Hubble did not discover the expansion of the universe. The interpretation of spectrum shifts as indicating an expanding universe was a gradual and collective process, to which Lemaître, de Sitter, Slipher, Lundmark, Silberstein, Wirtz, and others made relevant contributions. The cosmological constant was not abandoned by some supporters of the expansion of the universe, such as Friedmann and Lemaître.

There are still many further aspects of this process that might be fruitfully explored, some of which may be found in Kragh (2011) and Bagdonas (2011, 2015). The teacher with whom we worked followed up this course by joining a group in which such topics were debated.

It is likely that students will ask about unrelated scientific contents; at such moments, it is important for the teacher to be prepared to identify anachronistic perspectives and other historical distortions to in order to face those challenges in ways that contribute to students' learning processes.

17. *Choosing topics (within the selected episode) that inspire curiosity in the intended age bracket. The choice should not only consider technical and objective criteria, but should essentially involve and engage the students themselves:*

We tried to engage students with didactic resources by creating an educational game inspired by several board games popular among adolescents, such as War, Clue, Pandemic, and Civilization, among others. We also emphasized certain war-related biographical aspects of the scientists studied, with dramatic narrative elements intended to resemble action movies or police novels, which proved to especially attract boys, while girls seemed especially interested in women's participation in science and prized pacifism over bellicose disputes. Even so, gender-biased results contribute another challenge to the educational picture and should be addressed.

18. *Reflecting on the quantity and depth of the texts:*

Rather than having students read vast quantities of text, we tried to filter a great amount of information into cards containing reduced, yet concentrated information. This bore the risk of students thinking they were supposed to memorize the cards, which would have made the didactic sequence informative (rather than formative) and rendered it difficult to enact as planned. For this reason, it is always important to draw students' attention to the value of learning how to extract the most relevant information from the "sea of information" available, a skill which is more and more important in a contemporary world in which young people are constantly flooded with endless pieces of information by the Internet.

19. *A timeline with important historical events, some of which may be accompanied by "commercial" movies (as these are easily accessible to teachers and students), may help with the extent x depth dilemma, provided the historical approach is diachronic:*

We decided to privilege depth of historical period. However, this choice bore a loss in terms of extent, as students did not gain a broader idea of the situation of the given theories and ideas in the history of human thought. In using a movie-augmented timeline which notes other important ideas and events of the era, the teacher may explore both the place of the historical episode and other well-known names, places, and periods in the history of cosmology. Moreover, the teacher may explore the broader relationship of science with other areas of human knowledge, using movies to help with this contextualization of historical moments.

In using a timeline, it is important to approach each historical event diachronically, aiming to avoid a linear and presentist view of HPS.

20. *Each intended message about the nature of science can be addressed in different didactic activities and different historical episodes:*

The idea of potential political influences on science was designed to initially emerge in discussions involving the proposal of a boycott of German science after World War I. This was seen as a way to reveal the broader social influences impacting society as a whole, and to show that scientists are not immune to such influences. We also explored the effects of certain psychological and aesthetic influences on the individual beliefs of each scientist, as in the episode when Einstein, who was already a renowned scientist, rejected the proposal of a young, unknown man (Friedmann).

The importance of political factors was subsequently minimized, through emphasizing the facts that, although they were in different contexts, Friedmann, Lemaître, and Robertson nonetheless achieved the same results, and that their observations of redshifts were the essential factor in the choice between cosmological models.

Throughout this process, the different forms of political influences over science appeared in different contexts and in different moments of the selected historical episode, and then were gathered and organized in the final activity.

FINAL CONSIDERATIONS

Initially (in 2012), the TeHCO research group debated parameters intended to contribute to the process of the creation of a didactic sequence involving the history of cosmology. The author of those parameters was not part of this group and did not participate in that discussion. After classroom implementation, a new perspective on the parameters[9] enabled a reevaluation of the previous proposal, suggesting improvements in the teaching-learning sequence and evaluating the scope and limits of the parameters themselves.

Both the classroom results and this new reflection enabled us to review, extend, and organize the previously-established pedagogical objectives into three categories: concepts of cosmology, aspects of the NOS, and formative skills.

Our subsequent analysis showed that the didactic sequence on the history of cosmology mobilized more epistemological contents than initially intended, especially regarding issues about the NOS, such as the methodological pluralism of science. It also reflected the mobilization of procedural and attitudinal contents, such as group collaborative work, debate, and interpretation of texts. In addition to this, our analysis highlighted the necessity of taking historical and epistemological prerequisites into account: it is important to prepare students and teachers to identify reliable sources for conducting research in the history and philosophy of science. This will allow them to avoid the most common naive NOS conceptions, such as those of the experimental evidence of theories, isolated discoveries which occur on specific dates, and the reduction of the history of science to a set of facts, names, and dates to be memorized rather than discussed or interpreted.[10]

We also encountered one instance where it became necessary to adapt a parameter. The reflection suggested for parameter 12 (*to establish a connection between the results relevant to the construction of science with discarded contents or with contents that might currently be deemed "strange"*) did not apply well to the sequence of teaching and learning cosmology in the 20th century. The main reason for this is because the historical period in question is relatively recent. The risk of students seeing old theories as "strange" and the currently accepted ones as "normal" was further skewed in the case of modern and contemporary physics, since even currently accepted theories – such as the expansion of the universe, the creation of time and space in an instant defined as space-time, and other concepts involving relativity and quantum mechanics – may be considered "strange".

This reveals one reason why these parameters should not be seen as a simple recipe to be strictly followed. They were conceived as general reflections that must be adapted to different educational contexts and pedagogical purposes, as well as to different historical episodes. This characteristic makes them complex and less easy to use, but gives autonomy to each researcher. The deep reflections required in using the parameters allows to the researcher to analyze the consistency between the intended NOS views and those implicitly and explicitly transmitted by the historical narrative.

We noted that using a timeline,[11] with representative historical moments and thinkers from different civilizations and times, along with "commercial" movies easily accessible to teachers and students, provided an interesting visual resource for contextualizing the selected episode in a broader temporal perspective on the construction of cosmological knowledge. This can provide support for dealing with the dilemma or conflict of *extent versus depth.*

There is another difference between the research (involving the history of optics) that gave rise to the parameters and the sequence on the history of cosmology which involved choices for dealing with this *extent versus depth* dilemma. The parameters were created from a theoretical analysis and a case study of teaching aspects of the NOS by contextualizing different explanations for the nature of light in three different and well-defined historical episodes.[12] The sequence on cosmology, in turn, chose only one – albeit deeper – historical frame. It was thus not possible to address the different ideas of science and thoughts of philosophers, natural philosophers, and scientists of different periods and civilizations in a diachronic fashion. This difference in approach provided interesting questions for future research: which aspects of the NOS may be generalized for different periods of the history of science? What aspects may be characteristic of only some episodes? How can we explore the fact that one cannot generalize everything learned from one particular historical case to science as a whole? What kind of formative benefit might such debates offer to science education?

Despite concluding that the parameters provide a base for the construction and analysis of didactic proposals involving HPS, one should recognize their inherent complexity and the countless possibilities for their interpretation. This analysis was conducted in conjunction with the parameters' original author, facilitating their use and allowing her to clarify aspects that her original text had failed to explain. We hope it shows more possibilities for their use beyond those initially conceived, any of which will require a thorough and detailed analysis of the epistemic and non-epistemic aspects of each historical episode.

We have outlined our process of overcoming a range of obstacles to the educational use of the history of science in the hopes that our analysis may serve to lessen such difficulties for other researchers and teachers who may include this resource in their construction of educational material and courses involving historical perspectives.

NOTES

[1] Kuhn, in 1961, was already criticizing linearity and other historical distortions present in textbooks, despite recognizing their usefulness in quickly familiarizing the student with the current paradigm. He also criticizes the naive notion of scientific enterprise promoted by such distortion (Kuhn, 1997 [1961]).

[2] See Forato et al. (2015) on the omission of several features of Young's contributions to the wave theory of light in a short historical narrative, which has led many students to a misunderstanding of his role in the establishment of this theory and also has conveyed inadequate messages concerning NOS issues.

[3] See a detailed analysis in Forato et al. (2012b), and a synthesis in Forato et al. (2012a).

[4] Forato (2009, vol. 1, pp. 188–196) and synthesized in Forato and collaborators (2012b).

[5] The didactic material of the sequence of teaching and learning may be viewed on the website of the TeHCO Group: www.if.usp.br/tehco

[6] A virtual environment created to make material and information about the subject available.

[7] In spite of that, it is not rare to see science outreaches proposing that large particle accelerators, such as the LHC, are going to recreate the "Big Bang". To read criticism of this type of sensationalism, see Mário Novello, July 20, 2008, *Estado de São Paulo* newspaper. Available from http://www.estadao.com.br/noticias/suplementos,alarde-falso,208933,0.htm (accessed February 2013).

[8] Another interested analogy is the Expanding Rubber Band Universe (Soares, 2014), published after the implementation of our didactic sequence.

[9] The new analysis presented in this chapter was made by the author of the parameters and the main author of the history of cosmology course.

[10] For further details regarding historical distortions in textbooks, see Forato (2013), including examples of preparing teachers-in-training to identify naive NOS views on didactic materials.

[11] Available from http://www.nupic.fe.usp.br/Projetos%20e%20Materiais/o-eter-a-luz-e-a-natureza-da-ciencia (accessed March 17, 2015).

[12] Three different theories in the Classical Age (Leucippus, Empedocles, and Aristotle); debates between the vibrational perspective proposed by Christian Huygens and the corpuscular feature of light presented by Isaac Newton (end of 17th century); and controversies around the substitution of the corpuscular theory of light by the wave theory of light in the beginning of the 19th century, involving Thomas Young, Francois Arago, and Agustín Fresnel.

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Thaís Cyrino de Mello Forato
Department of Exact and Earth Sciences – Science Education
Federal University of São Paulo
São Paulo-SP, Brazil

Alexandre Bagdonas
Department of Exact Sciences
Federal University of Lavras (DEX UFLA)
Brazil

IVÃ GURGEL, MAURÍCIO PIETROCOLA, AND DANILO CARDOSO

12. THE ROLE OF NARRATIVE THINKING IN LEARNING SCIENTIFIC CONCEPTS

INTRODUCTION

According to the most recent educational perspectives, dogmatic teaching that is centered on the memorization of concepts and on problem solving methods which are meaningless for students should no longer have any place in our schools – especially at the elementary level. We must therefore replace propaedeutic education, which is aimed at preparing elementary school students for eventual scientific careers and such, with teaching that is more in line with current thinking on education. In contrast to the aforementioned educational concepts, many researchers have adopted the perspective of scientific literacy (SL) as more appropriate for the teaching of science. This concept has been increasingly utilized internationally to explore which methods, practices, and materials should ideally comprise the scientific education of all students (Roberts, 2007).

The notion of SL is especially relevant to discussions regarding proposals for curricula. Yore (2003) points out that the curricular reforms of the 1990s, which took place in Australia, Canada, New Zealand, the United Kingdom, and the United States, promoted a standard definition of SL as:

> the abilities and habits-of-mind required to construct understandings of science, to apply these big ideas to realistic problems and issues involving science, technology, society and the environment, and to inform and persuade other people to take action based on these science ideas. (Yore, 2003, p. 690)

This definition must be viewed as a sort of general directive for science teaching, since there is no consensus in the research community regarding the definition of SL (Roberts, 2007, p. 729). DeBoer (2000) states that SL is a broad concept that has had, and continues to have, a variety of meanings. Even so, he stresses that we can conclude that SL "has usually implied a broad and functional understanding of science for general education purposes and not preparation for specific scientific and technical careers" (p. 594).

Roberts (2007) contends that the diversity of meanings found for the concept of SL in the literature can be better comprehended if we consider the possibility of a political and intellectual tension inherent to scientific teaching. He refers to two legitimate, and potentially conflicting, curricular sources: "science subject matter itself and situations in which science can legitimately be seen to play a role in other human affairs" (Roberts, 2007, p. 729). For this author, there is a polarizing

M. Pietrocola & I. Gurgel (Eds.), Crossing the Border of the Traditional Science Curriculum, 207–225.

tendency in the SL literature between those who advocate for each of these two curricular schools of thought.

To represent this polarization, Roberts (2007) proposes two visions about SL. Vision I represents the more "internalist" view of science. It is concerned above all with the processes and products of science, and with designating ways of thought legitimized by science, such as the ability to interpret charts and use mathematical formulas to express concepts. In this vision, the objective of teaching science would be to enable the student to articulate these inherent characteristics of science and express him/herself in a scientific manner. Therefore, investigating different forms of scientific communication becomes fundamental in this context. In other words, in this view, thinking about the different languages involved in the construction, articulation, and communication of science is indispensable. Vision II, "externalist", is mainly interested in the possible role of science in the solution of everyday issues, and in developing social consciousness around the subjects involved in the process of science learning. According to the author, this more focused perspective on science and society is becoming more prominent in the literature.

Stephen Norris and Linda Philips (2003) swim against the tide, however, in leaning closer to vision I. In order to defend this stance, they base their argument on a distinction they make between a fundamental sense of SL – "reading and writing when the content is science" – and a derived sense of SL – "being knowledgeable, learned, and educated in science" (p. 224). They argue that the fundamental sense is central to SL, since it is a necessary condition for the development of other skills, including those related to situations which are not strictly scientific. In other words, in order for the student to express scientific thinking in the critical manner necessary for any discussion of social matters, it is necessary for him/her to first develop the fundamental sense. This shows that discussing the different forms of language and thought necessary to the development of scientific knowledge can be considered an important step in the quest for SL.

Many researchers have dedicated themselves to investigating different schools of thought among scientists. Investigations of possible causal relations in scientific explanations (Locattelli, 2006; Viennot, 2003), the role of formal and material analogies in the development of scientific models (Silva, 2007; Hesse, 1970), and the structural nature of mathematical language in physical thinking (Karam, 2012; Pietrocola, 2002) are examples of studies which attempt to comprehend certain defining aspects of the thoughts and languages of science. However, these studies focus, above all, on formal aspects related to scientific knowledge. Despite agreeing that these formal aspects are fundamental to the construction and structuring of science, we believe we can legitimately raise the following question: Can thoughts/languages which are not strictly formal exercise an important role in the construction and communication of science? We hold that the answer to this question is affirmative; and that a possible way of moving forward in this matter is to investigate the role of narratives in science and in its teaching.

We have shown in previous studies (Gurgel, 2010; Gurgel & Pietrocola, 2016) based on the analysis of original writings by Galileo, Oersted, and Ampère, that scientists create – at least in the contexts studied – texts with narrative traits. These narratives emerge, above all, in moments of scientific novelty. They emerge in the "gestation" of new ideas, an intermediary moment between the conception and the birth of a concept. It thus must be considered that the construction and constitution of an idea do not occur in a fully defined moment. In other words, a new idea is not merely the fruit of a one-time insight, although the latter could be important. A new concept is brought to existence by the construction of situations which introduce it as the narrative's core element. In other words, the characters of such narratives are the scientific entities themselves and the plot development is focused on establishing these characters, giving them specific meanings. In another study (Cardoso, 2015), the subject was existing narratives about the gestation of Albert Einstein's theory of general relativity. This study indicated that narratives and mathematical language are presented in a complementary way, especially in regards to one of Einstein's thought experiments, referred to in the literature as the rotating disc experiment.

The interest in narratives in science teaching has been increasing in recent years. In particular, "there is widespread use of narrative in scientific communication as a way to make science more relevant for the general audience" (Espinet et al., 2012, p. 1399). One of the works that spearheaded this theme was created by a group coordinated by Jon Ogborn (1996). These researchers showed that scientific explanations in the classroom can be considered narratives or stories. Other research, with varied objectives and theoretical foundations, has also shown interest in narratives in science education (Ribeiro & Martins, 2007; Klassen et al., 2007; Avraamidou & Osborne, 2009).

The goal of this chapter is to present an educational situation in which the students construct their own scientific narratives, in text form, from problematizations formulated by the activity's proponents. The details, including the context of application and the analysis of the narratives produced by the students, will be presented later on. First, we will introduce a few ideas that made up the foundation for this activity, in regards to the role of narratives in science education. There will be a particular emphasis on the ideas proposed by the US psychologist Jerome Bruner.

NARRATIVE AS A WAY OF THINKING

Jerome Bruner was born in 1915 in New York City. At 22, he graduated from Duke University (North Carolina) with a degree in psychology. A few years later, in 1941, he received his doctorate from Harvard University. During World War II, Bruner worked as a social psychologist in surveys about public opinion, advertising, and social behavior (Gardner, 2006, p. 90). After this period, in 1945, he became a teacher at Harvard, where he and George Miller founded the Center for Cognitive Studies (Leme, 2009). He remained at Harvard until 1970, when he accepted an invitation to work at Oxford University. He returned to Harvard in 1980. In 1991, he became a teacher at the New York University School of Law.

Bruner is considered one of the precursors of the field and continues to be one of the most important authors of cognitive psychology. The themes developed by this psychologist express, in a general sense, his quest to comprehend the mental activity of human beings. Studying the “mind” was not an obvious choice in the 1950s, since psychology had taken a fairly positivist path up to that point. It was believed that psychology should circumscribe its object of study to that which could be observed directly, and steer away from any issues involving subjectivity. Since psychology sought objectivity, the study of the mind was considered taboo, a stance which the cognitive revolution attempted to overcome. Therefore, “the first revolutionary movement of Cognitive Psychology screamed against this ‘objectivity’ and deviation from its true object of study, clamoring for a focus on the symbolic activities of human beings” (Correia, 2003, p. 507).

Despite participating in the cognitive revolution, Bruner started criticizing certain research paths taken by cognitive psychology, namely developmental psychology (Correia, 2003). One of his central criticisms focuses on its abandonment of important elements, such as the influence of culture and affection in psychological behavior (Leme, 2009, p. 14).

Bruner played an active role in the field of education, and particularly in science education. In 1959, for example, by invitation from the National Academy of Sciences, he presided at a meeting between researchers and educators that sought to formulate the basis for a new science curriculum. Among Bruner’s important contributions to education, his idea of a spiral curriculum stands out. Certain fundaments from this curriculum can be considered quite controversial, especially the contention that it is possible to teach any content to a child in an intellectually honest manner. In other words, it is not the nature of the content that hinders its learning, but the level of depth. Therefore, the idea of a spiral curriculum is that a particular content should be addressed and revisited several times in the education process, with increased depth at each turn. According to Leme (2009, p. 16), the subjacent thesis to the idea of spiral curriculum is that “intellectual activity, either of the scientist or the child in education, involves the same processes, the quest to comprehend. The difference is in the depth, not the nature of the subject”.

While in England in the 1970s, Bruner became increasingly interested in studies about child development, especially in regards to language. According to Leme (2009), Bruner had intensely studied Vygotsky’s work at this point in his intellectual trajectory. He was even one of the major publishers of that Belorussian’s work in the United States, having been invited to write the preface to Vygotsky’s book *Thought and Language*, by the latter’s colleague, Luria, who became a close friend (Leme, 2009, p.14). Upon returning to the US, Bruner showed great interest in social and cultural matters,

> […] rejecting the excessive computationalism of the cognitive perspective that he helped to found, he has directed attention to human narrative and interpretative capacities […] he has helped to launch yet a third revolution in

> psychology – one centered around the practice of cultural psychology. (Gardner, 2001, p. 91)

The role performed by narratives in human thought became one of the Bruner's main research interests, particularly from the 1980s on, when the author decided to organize and publish a collection of writings. This initiative resulted in the work *Actual Minds, Possible Worlds*, published in 1986. One of the writings included in this book is a major interest for this study: the chapter "Two Modes of Thought", which, according to the author, was put together at the request of the American Psychological Association (Bruner, 1986, p. ix). The core idea of this text is Bruner's proposition that there are two basic modes of thought, which he referred to as logical-scientific thinking – also called paradigmatic – and narrative thinking. To him, these are two modes of cognitive function, which provide different ways of organizing experience and constructing reality (Bruner, 1986, p. 11). In addition, he stresses that these modes of thought can be complementary, but are irreducible to each other.

One of the main distinctions Bruner makes between logical-scientific thought and narrative thought is their relation to the truth. While the former seeks universal truths by means of formal and empirical evidence, the latter pretends to have verisimilitude. With that, the American psychologist argues that many scientific hypotheses start out as short stories or metaphors, which achieve scientific maturity through a process of conversion by verification, whether formal or empirical (Bruner, 1986, p. 12). Years following his first publication about narratives, Bruner seemed convinced that this mode of thought could be, in fact, an important asset to science. This comprehension is owed, in part, to overcoming the view of science outlined by Karl Popper presented by Bruner in the first work cited. In *The Culture of Education*, the author makes his defense:

> […] you can falsify an awful lot of hypotheses, historians of science make clear, without bringing down the theory from which they have been derived. Which has suggested to many in recent years that grand theories in science are perhaps more story-like than we had expected. (Bruner, 1996, p. 122)

Bruner argues that "[…] we characteristically convert our efforts at scientific understanding into the form of narratives or, say, 'narrative heuristics'" (1996, p. 125). With the term "narrative heuristics", the American psychologist highlights – according to our reading – an essential characteristic of narratives: their ability to handle problematic situations. He claims that narrative provides a way to promote solutions to problems, but it is mainly a means to find them (Bruner, 2014, p.30). This process brings into question the knowledge we think of as "correct". In other words, narrative challenges our perception of the canon, in a sort of dialogue between what was expected and what actually occurred (Bruner, 2014/2002, pp. 24–25). According to Bruner: "Stories pivot on breached norms. That much is already clear. That places 'trouble' at the hub of narrative realities. Stories worth telling and worth construing are typically born in trouble" (1996, p. 136).

An important characteristic of the narrative is how it presents a consigned structure of time; in other words, the passage of time in a narrative is not defined by a clock, but by the course of crucial events – at least in beginning, middle, and end. Bruner states that "what underlies our grasp of narrative is a 'mental model' of its aspectual durativity – time that is bounded not simply by clocks but by the humanly relevant actions that occur within its limits" (Bruner, 1996, p. 133). Narratives deal with details. Stories are interpreted as if they fall into genres, and these interpretations are influenced by cultural and historical contexts. But what are genres? To the author, "on the one hand, a genre 'exists' in a text – in its plot and its way of telling. On the other, it 'exists' as a way of making sense of a text – as some sort of 'representation' of the world" (Bruner, 1996, p. 135). Comedy, tragedy, romance, irony, and autobiography are examples of genres. Bruner goes on to state that genres "are culturally specialized ways of both envisaging and communicating about the human condition" (1996, p. 136).

Narrative is a method – according to Bruner one of the main ones – that we use to interpret reality. The very etymology of the word "narrate" indicates that narrative can go beyond telling something already known. This word derives from both *narrare*, which is most strictly defined as telling something, and *gnarus*, which means "to know in a particular way". In other words, the construction of narratives can be understood as a particular way of knowing reality. It is worth noting that this process inherently regards a constructed reality rather than having, as a naive empiricist would dream of, a direct line to the prime reality. Our access to the world occurs via mediations, through symbolic constructions. To Bruner, narrative is one such means of access. He defends the narrative as a form of organizing the outside world.

Bruner considers narrative as the universal currency between our self and the social world (Correia, 2003, p. 509), and between the individual and the cultural (Gurgel, 2010). Therefore, "exploring the nature of narrative, as long as we are sensitive to the context it was revealed in, is to explore a mode of thought" (Correia, 2003, p. 509). This mode of thought, which represents both the individual and the cultural, allows the new to emerge by reconstructing what was established in a dialectic process between imagination and memory.

Therefore, we can define the elaboration of narratives as a creation process based on imagination, which nonetheless entails an awareness of reality and established cultural forms (Gurgel, 2010). That being said, we consider the narrative to be of great interest to science education, particularly because it allows the student to have an active role in the composition of knowledge, since the student him/herself can create a narrative that may be considered an original, intellectual construction without losing sight of science as the basis for this construction. This would fit Bruner's assessment that schools should treat knowledge as a construction to fulfill the potentialities wrought by culture (Leme, 2009, p. 17). In addition, schools should give students the tools to intervene in this culture in a dynamic process, since, to Bruner, education

> is not simply a technical business of well-managed information processing, not even simply a matter of applying "learning theories" to the classroom or using the results of subject-centered "achievement testing". It is a complex pursuit of fitting a culture to the needs of its members, and its members and their ways of knowing to the needs of the culture. (Bruner, 1996, p. 43).

Although the importance of narratives to science education can be acknowledged, it is no easy task to realize their role in scientific knowledge or even how they may offer a means of comprehension for certain school subjects such as physics. This is the result of the strong positivist point of view that continues to permeate science education. In a general sense, education is reduced to the mastery of formal aspects of knowledge, such as the ability to operate within the laws described by mathematical formulations. Therefore, we will attempt to contribute to this debate by introducing a proposal for didactic activity in which education is treated as a cultural manifestation (Gurgel & Watanabe, 2012). In it, comprehension of the concept of electric charge is constructed via narratives elaborated by the students themselves.

NARRATIVES IN A PHYSICS CLASS

The teaching scenario described in this section occurred in the year 2009, in a school located in São Paulo, Brazil which developed a curriculum that stood out quite a bit from the usual standards. Aside from counting on teachers with good academic training, the political-pedagogical plan included interdisciplinary activities, in which a scientific subject, such as physics, interacted with literature, the arts, and history. In the context of natural science topics, discussions were sought on the nature of sciences with emphases on science, technology, and society. This provided a suitable environment for the development of humanist activities.

The activity occurred in a first-year high school classroom comprised of 25 students, all within the expected age range for this level of schooling (14–15 years old). For the most part, the students were cooperative and enjoyed the physics course as offered by the teacher.

At this point in their educations, these students had already begun studying electricity, having been introduced to the voltaic pile as an energy source. They had been presented with an atomic model based on the exchange of ions, and had then directly explored notions of electrodynamics, such as current, resistance, and voltage, formalizing Ohm's law. This was followed by discussions about the potency consumed by electrical devices and the voltage produced by the current in that process. To provide explanatory context, students had explored the electricity present in our homes, discussing the energy consumed and the systems used for the distribution of electricity.

Our learning scenario was presented in this context, without showing the students the concept of electric charge and its implications. However, in talking with the teacher, we had decided that it would be important to introduce the class to the concept of charged particles, such as protons and electrons, in order to better prepare them for the activity. This led to a classroom reading of a text entitled "Interview with the Electron".[1] This reading explicitly introduces the electron as a physical concept, but, in its "interview", only a few characteristics are discussed. The text discusses the electron as an elementary particle and raises the notion of electric attraction. The text narrates experiences such as the charging of a plastic straw with electricity as possible ways for students to verify the effect for themselves. After this presentation, the electron, as the text's main character, affirms that it can be a source for the explanation of many phenomena, such as changes in physical state, the rigidity of a given material, and the reflection of light. However, it does not actually explain these effects.

In a class that took place on November 12, 2009, the students read the aforementioned text and answered the following question:

> Based on the previous text and your knowledge, list the phenomena we can verify in our everyday life based on the electron's properties. List at least eight examples.

The purpose of this question was to make the students extrapolate from that which had been presented in the text itself. This could have been based on their knowledge of previous classes or even hypotheses of their own conception. Their answers included elements such as: heating water; computer manufacturing; a shower's inner workings; electric conductivity; the heating of a spoon in contact with a source of heat; the light entering our homes; the melting of chocolate; the construction of a wall; leaning and stepping on something consistently while walking; a magnet's attraction to metal; the mechanics of electronic devices; the shock we feel on cold days, and more.

We can see from these responses that the students did not limit themselves to what was written in the text. This is positive data, because it will be reflected in their respective textual constructions. Some effects were tied to thermodynamics and electrodynamics, topics they had studied throughout the year. The influence from these latter foci resulted in the superimposing of effects more directly linked to the electron's properties with atomic and molecular properties that involve, for example, phase changes. We chose to accept these answers because we considered it valid to look at the electron within this context.

This activity was finished in the same class and was followed up by assigning students a narrative production as homework. The task was presented as follows:

> Imagine that you wake up one day and the electrons of the objects around you 'are on strike', in other words, they are not producing their usual effects on the phenomena in your handouts. Describe what this day would be like (try to imagine the most unusual effects from this, but keep in mind that the atoms of your body and those of your classmates' bodies are behaving normally and this only affects the objects around you). Write at least one page about it.

Our goal was to make the class reflect on what an electron is and how electrons are tied to diverse effects around us. However, we wanted this to be done in such a way that the students would extrapolate from the most immediate perceptions of everyday life. Our strategy was to make them consider the repercussions of the nonexistence of these electrons. We surmised that the best way to think about the presence of electrons in the world around us might well be to consider the exact opposite – their absence.

Next, we will show and analyze the texts written by the students. Since there were 25 texts in total, we opted to discuss only a sample. Even so, there is no major loss in scope, since many narratives wound up being similar and the data began to overlap. We concluded that an exhaustive analysis that included all input would provide little benefit to our study. Instead, texts were selected in an attempt to consider the maximum variety of textual profiles.

Student 1

> I woke up for what promised to be a normal day, but it turned out to be, in fact, the weirdest day of my life.
> First off, I was late, because the alarm clock didn't work. That was odd, because I changed the batteries last night. After that, I found out none of the lights were working, or any other electronic devices, including the ones that used batteries.
> I ate breakfast and asked mom to take me to school. We got in the car, but the battery wasn't working.
> I walked to school and, to my surprise, none of the cars were working. The gasoline simply wasn't reacting to the oxygen, there was no combustion!
> Once I got to school, without electricity, the first class was chemistry. The teacher explained acidic reactions and the basis for creating salts, then we went to do experiments in the lab. To our surprise, the reactions just weren't happening, freaking the teacher out.
> The next class was physics, also in the lab. After an explanation about electromagnetic forces, we did a few experiments with magnets, but not a single magnet was 'working'. We also tried to electrify a balloon by friction, but our efforts were in vain. This was the last straw for the teachers who declared the end of the school day until they could investigate these events.
> 'God is punishing us!' said the religion studies teacher, while the others tried to calm her down.
> As the day went by, the events became even more bizarre. Materials lost their 'hardness', it was possible to shatter an iron bar like it was made of Styrofoam, things started to lose their ability to refract light.
> Then I thought, 'That's it! The electrons are losing their function! That's why the electricity, the magnets, and chemical reactions aren't working!'
> But it was too late, the electrons in my body stopped working. I immediately died.
> Now I write this from heaven, the teacher was right: God was punishing us!

This text is very well written. It has continuity, which can be seen by the ending which reveals why the classroom experiments were not working. The author revisits a previous “enigmatic” event and reveals its cause. Not only that, the entire text reflects on electrical events, giving it a strong sense of unity. However, the text is not repetitive, because the events add up to a real development in the story. This shows the progression of the narrative.

Aside from these elements, the text has no contradictions. Although we may assume that all the events mentioned could occur simultaneously – as, from a physical point of view, they should– the author addresses them be revealing each aspect bit by bit. This also shows the articulation of the text. For example, noticing that the car’s battery was not working was followed by the realization that the engine was not producing any combustion, either. These are distinct nuggets of information which are soon linked. In the same way, the phenomena that did not occur in the physics and chemistry classes demonstrate the build-up to a connection that is not merely elementary.

As for external elements, we see that the author intends to do more than merely inform the reader about the physical traits of the entity involved. He meets the requirement of envisioning what would have actually occurred differently in his imagined scenario. This is highlighted by the ways in which all of the agents of the plot react to the events. The teachers themselves are alarmed. This also gives the text a good level of legitimacy and fulfills its pre-established didactical role.

All the events brought up are coherent with what could occur in a school day and they all involve phenomena relevant to the core subject: electricity. Aside from that, the writing contains a lot of non-trivial information. Since this is a requested narrative in the context of a course about electricity in the subject of physics, the connections the student makes to chemistry concepts (when mentioning the car battery, the fuel reactions, and the formation of salts) greatly exceed what was expected in terms of information. The student does not limit himself to a repetition of the text about the electron, even when it is referred to via the iron’s loss of hardness and the absence of light refraction. This also demonstrates the richness of intertextual elements in the work.

In regards to narrative aspects, we initially have a plot rich in facts. This is an assessment related to the informational elements of the writing. However, we can see the text’s introduction foreshadows what is to come. This can be seen when the student tells us how it was a strange day, the weirdest in his life. In this way, the story announces its complicating factor, regarding how the facts of the narrative will be developed. This is continued with the story revealing all of the day’s strange occurrences. At first, we only learn that objects are not working. However, the story gains weight when scientific phenomena do not work as they should in the student’s classes. This leads up to the climax, in which the teachers themselves become desperate. Only near the end is the cause behind all the events revealed: The electrons are on strike. This revelation alone could make up a resolution in regards to the semantic unit of the text. However, there is another complication: The student’s own electrons “join” the strike. This leads to a tragicomic ending, the student’s death. We can see that all steps of a narrative’s plot have been achieved.

The student is an important character because he himself is the narrator. However, if we ask who carries out the key actions in the story, or who is responsible for every occurrence, we see it is clearly the electrons. Therefore, according to the very definition of a character – as an agent responsible for events – we could consider the electrons as protagonists. Finally, the setting where all the action occurs is part of the student's everyday life – his home, his school, etc. This element shows that he can look in 'uncommon' ways at things which are 'common' to his life, showing them in a new light.

To summarize, we can conclude that this is a well-written text developed in a narrative form. The text is coherent and cohesive, with its semantic unit established around the physical meaning of the concept of electrons. This is one of the most important elements of verification for our study. Aside from that, we can see that from a narrative point of view, the electron itself is the central character, which allows us to define this text as scientific.

Student 2

> If this happened, maybe I would not be shocked today, because my body would not be electrified.
> All objects (or at least most of them) would be reduced to dust, because this is one of the electron's functions, to 'hold' materials together.
> If this was a cold day, and I removed my wool sweater, there would be no snapping sounds, because the electrons are 'on strike'. I could even suffer an accident.
> At school, the teacher could use me as an 'experimental object´ for the first year of high school. Several materials could stick to my body.
> The TV screen at home would not show any images and I could not groom myself in front of the mirror, because I would not see my reflection.
> If I went to the cantina to drink cold juice, ice would not melt in the glass or spaghetti would turn into soup when cooked.
> If I went camping with my friends and needed to light a fire like a caveman, I would not be able to produce friction between the objects needed.
> I arrived at the conclusion that a day without electrons is tough, because they are responsible for a good part of our everyday activities.
> I hope this strike ends soon, otherwise I won't be able to do my physics homework on the PC; there would be no image on the screen.
> Turning the lights on would be impossible, too, so how am I gonna do my homework in the dark?!
> On the other hand, it could be fun, I could walk through the wall; my house would not need doors and windows.

This text has little continuity. Each paragraph portrays an event with no connection to the previous one. We can recognize a running theme since it always refers to electric phenomena, but the text is fragmented. However, there is progression, since even with the breaks there is little repetition. Only the first and second paragraphs show repetition. In the first one, the student refers to the body being charged and then to the charge of the sweater. It is worth noting that what could be a point of continuity in the text is presented in a desultory way. There is no contradiction, mainly because the links between the story's events are very faint. This also means the text has little articulation.

The author has the intention of showing the different nature of this day and does so in an acceptable way. Although there is little immersion, the writing is not limited to exposition alone. This allows it to conform to the proposed didactic situation. Despite the lack of articulation, there are informative aspects. At first, it introduces elements from "Interview with the Electron", but the following moments transcend what was shown in class. This occurs when she writes that the teacher could stick objects to her during a classroom experiment and when she claims she would not need doors and windows in her home. This makes it difficult to evaluate the intertextuality, because this is information we do not encounter in other classes of this course.

From a narrative point of view, we could say she has a fact-filled plot, but there is no build-up. The text has no introduction, skipping straight to development. But, since the information is disjointed, there is no developing conflict. There is closure, because after going over several life-complicating factors, the student concludes positively by stating that, on the other hand, she would not need doors and windows. However, given its lack of cohesion, the text cannot be said to have much of a plot.

Again, the narrator is the character who experiences the facts, but we can affirm that the main character is actually the electron – the agent behind it all. The setting is the student's everyday life, meaning that this student also retreads the environment in which she lives in a new way.

Generally speaking, even though it is textually weak, the semantic unit is maintained; the discussion about electric phenomena persists. The element that supports this unit, albeit weakly, is the use of electron as the narrative's main character. However, its deficiency in articulation demonstrates a dearth of reflection as to how the character is linked to the chain of events at the source.

Student 3

> 23:31
> It was almost midnight and I was studying math, darn math that wouldn't enter my brain, when I gave up!
> 23:39
> I quit, because it wasn't making any difference. I was coming down the steps to drink some water, when I noticed something weird… It was like everything was vanishing, disintegrating. I thought I was just getting sleepy.
> 23:58
> That wasn't right.
> It wasn't the drowsiness that was consuming me.
> 24:00

> Darkness.
> My clothes, sheets, bed. Nothing was there anymore, just my necklace, so sentimental, I consider it part of my body.
> 24:07
> 50 meters from me.
> I recognized her by the pale skin of her naked body. It was my neighbor, who was more freaked out than me.
> 01:30
> Over 200 people, all naked, together, nowhere, with nothing.

This is a continuous text in which the events are linked together. This happens from the very beginning as the student shows her struggle to study, which persists as everything starts to change. Aside from that, the possibility of drowsiness mentioned previously is reconsidered to reveal that drowsiness was not the cause behind the events. There is little progression because, even without repetition, few facts are presented. However, the text does not contradict itself and that, more importantly, makes it well articulated.

The intention is to show how the day, or night in this case, is different. This is very well conveyed by the text's dramatic impact. Therefore, this text is not merely informative. That makes it acceptable, since it conforms to the situation proposed in the activity.

The text is not very informative because it contains few facts, which also gives it little intertextuality. However, there are certain informative aspects, since, in showing in depth how all things come undone, the author transcends the expected mode of seeing the central fact.

The text is, however, extremely interesting from a narrative point of view. It starts with an introductory scene. The drama is well developed, with a weirdness that becomes increasingly complicated until, at midnight, it reaches its climax in which everything falls apart. This narrative's closure does not bring resolution, but it fulfills its role in a poetic fashion, when the student places everyone "nowhere, with nothing". While this is centered on fact, the plot development makes it very significant.

As a character, the electron remains hidden, yet the plot is centered on it, making it the protagonist nonetheless. In this case, the setting is more limited, since everything happens in the environs of the narrator's house. But even in this limited setting, this is still a form of reviewing a 'common', mundane reality in terms of the changes brought by the electrons' strike.

Although it is a short text, it is very coherent and is developed with great creativity. Despite this, and its dramatic appeal, it does not lose its scientific aspect, since everything in the narrative was the result of electrons going on strike.

Student 4

> A day in which objects' electrons go on strike would be funny if it didn't bring up a problem.

> Upon waking up and trying to turn my room's lights on, my finger would stick to the light switch because my body's electrons would attract the switch's protons. Although that would be annoying, I could still escape that but then I would be fighting the sheets stubbornly clinging to my body.
> From then on, everything would be a nightmare. My walk to the bathroom would become a game of tag in which I'm 'it' and the catchers are the objects along the way.
> And the whole day would go on with everybody attracting things as if there was some gravitational force inside them all.
> But something good would come from this, nobody would be shocked in what would be a really complicated day. Everybody on the streets would attract objects or be attracted by them.
> Aside from that, there would be no electricity as long as the electrons remained 'on strike'.
> If this day happened for real, we would get ourselves in all sorts of trouble and it would be really lucky if nothing more serious happened.
> Even walking would be a struggle because there would be no attrition, meaning that all we could do was wait until the strike was over.

This text retreads the problem of physical attraction several times. Even when there is a break from the subject, once the student mentions shock, he immediately goes back to the attraction issue. Therefore, there is good continuity in the text. Even though he is very focused on attraction between the objects, there is progression because the situations vary, that is, the context in which they are featured changes. There are no contradictory elements. Even if the issue of attrition by the end of the text is a little vague, it does not go against elements shown in the text itself. Therefore, there is good articulation in its development.

The author's intention, as expected, is to show how the loss of electrons complicates everything and how such a day would be different. Therefore, this text is acceptable in regards to our pre-established objectives and in accordance with the assignment proposed.

The text contains little information in regard to the theme. However, it focuses on an unusual situation, the attraction of the body's electrons to all the protons in the world, since only the electrons in objects went on strike. This ends up compensating for the lack of thematic variation. Since the text has little variation in information, it also has little intertextuality.

From a narrative standpoint, the text constructs an introduction by informing the reader about the "funny" day to follow. Its development elaborates on the strangeness of the day. Although the situation is aggravated in the first half of the text, there is no climax in the narrative. This results in a somewhat deficient ending, in which the student states they can only wait until the 'strike' ends.

However, the pattern of characters is not the same as that found in previous writings. Here, the proton is explicitly brought into play, which is an interesting approach, rendering the protons' attraction to the electrons which continue to operate in the bodies of people the focus of the narration. Therefore, we have two conceptual protagonists in the plot. The narrator character is the student himself. And the setting is the student's everyday life.

The text uses a semantic unit in regards to the concept of electric charge. The student manages to include it in interesting situations and goes in an unusual direction when addressing the protons' behavior toward the electrons of her body. This limits the events of the story a bit, but also makes it more cohesive, and the vision it wants to convey becomes increasingly clear over the course of the narrative. It is interesting to note that, with the introduction of two main characters, the process of significance emerges from the mutual relationship between these two. This reinforces the idea that the characters have a large role in the construction of the text's semantic unit.

Student 5

> One day, I woke up like I would on any other day. But, to my surprise, this wasn't going to be such a normal day. For starters, I was up late, because my digital alarm didn't ring. After that, I found out we had no electricity at home. I thought the lack of power was only happening at home, because I couldn't turn the TV or the PC on.
>
> On my way to school, I couldn't take the car, because it wasn't working either, just like all the other transportation methods available.
>
> When I got to school, many classmates were chatting about the weird phenomena going on. Since many students and teachers were also confused, the physics teacher, who had figured out the cause of this phenomena, decided to give an explanatory lecture.
>
> In this lecture, she explained that the electrons were on 'strike'. To do that, she needed to explain that an electron is a scientific concept known mainly for the electrical phenomena it produces. These electrical phenomena are, in turn, caused by a property, that of electric charge. She explained that many phenomena are caused by electrons, such as the energy we use at home, the attraction of certain materials by others, the image that appears on the TV screen and the computer, and even the shocks we feel in winter.
>
> After leaving the school, many students, with their doubts clarified, went home and began observing the phenomena that 'were missing', in other words, phenomena caused by electrons. At home, we couldn't eat anything warm and a lot of food went bad because there was no power to the fridge. Something I found very interesting was that there was no change in the physical state of the materials. Ice wouldn't melt, it didn't turn liquid. Something else that caught my eye was that all objects weren't solid, I could get my hand through them! I thought that was the most amazing thing about that day.
>
> At night, to close the day with even more weirdness, there was a storm, with its trademark rain and thundering sounds, but there was no lightning, since this is also caused by thousands of electrons. Therefore, I concluded that

electrons make up the vast majority of things and life without them is impossible, and really, really weird.

The text has continuity. The element that most embodies this is when the teacher explains what's happening that day. Previously-described strange phenomena were thus revisited, having gained an explanation. There is good progression, with the addition of new events as the text goes on. However, there is an element of contradiction. Near the ending, the student claims that ice doesn't melt. After that, he states that objects are not solid. Although the student intends at one point to refer to the electron's role in chemical reactions and physical state changes, he later states that these connections are undone, creating a contradiction, at least in phrasing. In the end, this makes the text somewhat disjointed.

His intention is to show how different such a day would be and thus the text is acceptable vis-à-vis what we intended for the project; it complies with the school assignment for the same reason. Although there are many facts, the text is not very informative, which can see through its intertextual elements. The entire section dedicated to the teacher's explanation is based on the text read in class. There aren't many new elements brought to the table. The only divergence from what was discussed in class is the claim that he could move his hand through objects. It is noteworthy that the author himself mentions this as the most interesting part of the day. This shows that this perception was quite new to him.

From a narrative standpoint, the text has good initial exposition, in which the student himself 'reveals' the different facts. The story is developed in a progressive manner. After realizing the problem is not limited to his home, but also extends to transportation, the student's arrival at school escalates the narrative gravity: Everybody inside is desperate, including the teachers. However, the teacher's long exposition and the text's simple closure remove the climactic focus from the previous situation.

Once again, the electron is the main character and the student is the narrator. The setting varies between the student's home and the school. The environment is the student's everyday life, and the entire written work consists of things that exist around him.

FINAL CONSIDERATIONS

We started this study with the following question: *Can thoughts/languages which are not strictly formal exercise an important role in the construction and communication of science?*

The natural sciences seek, whenever possible, to comprehend the most intimate structures of reality. This is a complex challenge, given the difficulties in thinking of ways to produce representations of a world inaccessible to the senses. It involves a process of symbolic creation that demands the most of our cognitive and cultural faculties.

However, "learning to speak science" is often reduced to an attempt to compile uses of formal propositions. In other words, labored concepts are used to enunciate empty realities. Therefore, we contend that the relationships between thought, reality, and language should be taken into account when proposing educational activities.

According to Jerome Bruner's reflections, a narrative is more than a way of communicating something to a person. It is also configured as an attempt to make reality intelligible, turning it into a means of passing on knowledge. Therefore, we can surmise that narrative thought can perform an important role in the development and learning of scientific knowledge.

Science, especially physics, creates many entities which become the basis for explanations. As part of this project, the authors were able to verify that narratives are means of characterizing these entities and turning them into constructs capable of producing understanding about the world. Characters are not just created for a story, they are created in a story. It is during the course of events that the characters' traits are revealed.

The narratives shown above have diverse characteristics, as indicated by our analyses. However, what makes them interesting as didactical resources is the fact that a physical entity, in this case the electron, is the protagonist that structures the narrative. This means that the concept is not merely "applied to everyday situations", but that the dynamic of story building gives the concept a key role for understanding the natural world.

We can affirm that nearly all of the texts created by students in this class were very good. The fact they are students at a well-structured school with a humanist-inclined curriculum really helped in making this accomplishment possible. However, it is also worth noting that some prior familiarity with the concepts of electricity and magnetism was a fundamental factor, providing a minimum repertoire of knowledge with which to engage in this activity. In addition, the inclusion of the supplemental text, "Interview with the Electron", provided strong levels of intertextuality, laying important groundwork for student fulfillment of the assignment.

We hope the activity presented and studied here will serve as an example for teachers in conceiving new initiatives for their classes.

NOTES

[1] Source: http://www.nupic.fe.usp.br/Projetos%20e%20Materiais/Curso-de-Onda-Particula/textos-professor/BlocoIII%20-%20Eletricidade%20e%20magnetismo.pdf

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Ivã Gurgel
Department of Experimental Physics
Institute of Physics
University of São Paulo
São Paulo-SP, Brazil

Maurício Pietrocola
Department of Teaching Methodology and Comparative Education
School of Education of the University of São Paulo
São Paulo-SP, Brazil

Danilo Cardoso
Post Graduate Program in Science Education
University of São Paulo
São Paulo-SP, Brazil

MARISTELA DO NASCIMENTO ROCHA AND IVÃ GURGEL

13. INTERWOVEN THOUGHTS

Rethinking the Current Picture of Physics Knowledge

ASSUMPTIONS OF CURRICULUM PROPOSALS

No educational proposal is possible without certain underlying commitments, which may be explicit or implicit. Whether they are political, ideological, social, metaphysical, epistemological, and/or educational in nature, all such commitments influence our physics teaching practices in particular ways. Usually, a preoccupation with social problems will lead educators to make proposals related to the influence of science in society; those who criticize traditional ways of learning and teaching will tend to propose dialogical and interactive classes; those who are worried about the training of engineers will suggest instruction in problem-solving exercises; those who are preoccupied with civic participation, the teaching of physics concepts related to daily life; and with naïve conceptions about physics, themes involving the history and philosophy of science, and so on.

In recent proposals, humanistic perspectives on education which call attention to the historical and social character of science have been dominant (Aikenhead, 2007). Given this point of view, the emerging physics curriculum has been concerned with the formation of citizens and the identification of those aspects of scientific knowledge that can serve this purpose; it takes into account not only social inclusion, but also social change, as is the case in the science, technology and society (STS) perspective and the current research on relevance (Aikenhead, 2007). Likewise, the same tendency is found in student-centered proposals.

However, even if our gaze is concentrated on a certain commitment, it is not possible to ignore the existence of others. It is important to note that humanistic proposals might not always be compatible with the priorities and values of other pictures of the world,[1] since other types of commitments will also be stakeholders in the cultures of schools. This explains why educational research alone cannot change a given educational system. However, there is still one commitment to which we have not given sufficient attention: our own views on physics knowledge. We have questioned the structure of educational activities, conceptions about the nature of science, and the relations between science and technology; in addition, we have changed strategies for learning new concepts; but we have not yet questioned our own conceptions of physics knowledge, of what a scientific concept is, or what it truly means to learn a concept. Our view of physics knowledge is fixed.

M. Pietrocola & I. Gurgel (Eds.), Crossing the Border of the Traditional Science Curriculum, 227–247.

A lack of attention to this commitment can prevent humanist proposals from being, in fact, humanist, since the knowledge created by physics is the basis for its importance to education. The only possible outlook on physics knowledge in science education seems to be the one provided by the final formalization of theories, which are presented by physicists as the product of their practices. The common conception of physics knowledge is that it is a tool used to classify phenomena and to make mathematical descriptions from well-defined principles. This conception is a generalization of the picture presented in textbooks, as in the following view of Newtonian mechanics[2]:

> The science of mechanics seeks to provide a precise and consistent description of the dynamics of particles and systems of particles, that is, a set of physical laws mathematically describing the motion of bodies and aggregates of bodies. For this, we need certain fundamental concepts such as distance and time. The combination of the concepts of distance and time allows us to define the velocity and acceleration of a particle. (Thornton & Marion, 2004, p. 48)

This quote is the first paragraph about classical mechanics in an influential textbook. This content is followed by definitions of Newton's three laws, the concept of the frame of reference, the equation of motion for a particle, and conservation theorems, among others, which form the basis for the exercises and problems involving mathematical descriptions and explanations of motion at the end of the chapter. Oddly enough, this is the same picture of knowledge found in conceptual learning research in classical mechanics, although with less mathematical rigor and performed with what would be considered innovative approaches. This is the case even when the inclusion of historical and philosophical contents is considered as a strategy for learning physics:

> Responses [before the conceptual classes] showed how they thought of acceleration as 'going fast' or 'a big force' rather than 'a change in velocity'. (…) Once students understood the difference between constant and changing velocity, Galileo's inclined-plane experiment was conducted to demonstrate the acceleration concept. (Seker & Welsh, 2006, p. 69)

> One simple example [of difficulties in learning] is with common misunderstandings of Newton's third law (…): 'For every action there is an equal and opposite reaction'. This gives no indication about the meaning of action and reaction (…). Newton himself stated the law in another, more helpful and less misleading, way: 'the mutual actions of two bodies upon each other are always equal, and directed to contrary parts'. (Gauld, 2012, p. 78)

Hence, even in research which is in line with the current humanistic tendencies in science education, to understand a physics concept is to be able to enunciate its formal definition and to apply it in exercises designed for this purpose. 'Acceleration' is equated to a change in velocity. Understanding Newton's third law means identifying mutual actions between forces and their opposite directions. If physics language is always fixed in this manner, only content coming from science studies can provide humanistic features, and only a utilitarian use of concepts can serve the purpose of a humanistic education. It is a contradiction that physicist's practices have humanistic features, but their concepts and language do not.

The commitment to this fixed idea of physics knowledge is the basis for current utilitarian approaches to the physics curriculum, which focuses on certain applications of physical concepts deemed useful in our contemporary lives: "canonical science must be transformed into knowledge very different in character from the 'pure science' knowledge of the science curriculum; as one moves from pure science for explaining and describing, to 'practical science' content for action" (Aikenhead, 2007, p. 887). In the current utilitarian approaches, physics knowledge is viewed in itself as non-humanist, fixed, timeless, dogmatic, and useful for humanist purposes only for solving specific issues in our lives.

Although humanistic characteristics are recognized as constituents of scientific practices, such as those present in the consensus view of the nature of science[3]; scientific concepts and language do not contain these features in their final forms. This same conception of scientific knowledge has led educators to think that the humanistic features of science can only be learned through the inclusion of science studies content, which corresponds to ways of thinking which diverge from those considered scientific per se. As a consequence, physics knowledge has no direct role in a humanistic education. Physicist practices contain humanistic features, but the physics concepts resulting from these practices do not. If, on the one hand, conceptual learning and teaching are being renewed by the insertion of HPS content (Teixeira, Greca, & Freire Jr., 2012), on the other hand, conceptual understanding is still unrelated to its historical-philosophical dimensions. In this context, the desired ways of understanding concepts remain similar to the traditional ones[4]: they lack humanistic features, and thus do not allow students to be autonomous and critical thinkers with regard to learning physics knowledge.

We cannot deny that the proposals for humanizing science education have been successful in some regards. However, this success is very limited, since such proposals are still based on a limited picture of knowledge. This limitation is in turn based on an ingenuous picture of language, as we are going to demonstrate in the next sections, which incorporate Ludwig Wittgenstein's (1889–1851) philosophy of language. If, instead of looking at the final formalization of theories, we explore the ways physicists use concepts in their practices, then we will frame physics knowledge as constituting a form of life, an approach which creates new possibilities for the sort of deep thinking and knowing that cannot be learned only from isolated applications of concepts. We are also going to demonstrate how overcoming our current picture of physics knowledge will lead us to perceive it as composed by different traditions of thinking, which go beyond what is presented in the formalized theories. We are going to exemplify this by showing how the philosophical way of thinking is interwoven with ways of thinking in physics, allowing us to change the current role of philosophy in physics teaching and to conceive of physics concepts from a humanistic perspective, in which students can be autonomous and critical thinkers with regard to the learning of physics knowledge. Finally, taking this relationship into account, we are going to suggest a new approach to classical mechanics.

LANGUAGE: AN AGREEMENT BETWEEN FORMS OF LIFE

The relationship between language, thinking, and the world was Ludwig Wittgenstein's major concern. In this section, we are going to consider his second phase of thought, which is represented by his Philosophical Investigations (PI) (1953). Wittgenstein criticized the common model of language as representation, which considers words as labels naming the objects they represent, just as the word 'table' names the object 'table'. In this model, the meaning of each word in our language is "the object for which the word stands" (PI, §1). Our discourse would thus be composed of connections between words that have the sole function of representing reality and thoughts with an independent existence from ourselves.

For Wittgenstein, we tend to generalize this representational use of words to all that we call language (PI, §11). Since there are so many words naming objects, we tend to believe that all words are used in the same way. However, this tendency is caused by the lack of a panoramic view of the ways in which we use words, since we do not always use them as a reference:

> (…) we do the most various things with our sentences. Think of exclamations alone, with their completely different functions:
> Water!
> Away!
> Ow!
> Help!
> Fine!
> No!
> Are you still inclined to call these words 'names of objects'? (PI, §27)

Additionally, the reference model of language also contains the idea that language can only name and describe (Hacker & Backer, 1986). However, there are other types of actions performed by language, such as doubting, formulating hypotheses, asking, thanking, calculating, and questioning (PI, §23). Perceiving language as mere representation is not incorrect, but it is limited, since there are other uses of words as well. Wittgenstein's intention is to perform a sort of "therapy" for the picture of language as representation, by inviting the reader to view language in a panoramic way. Observing how language works in other linguistic contexts is useful for showing us how not to fall prey to generalizations.

When we realize that words have different uses, we also realize that they are surrounded by conventional rules. We can teach someone how to name objects with ostensive gestures, but this is not adequate for teaching that person how to use the word in different contexts. By the way, even in this case it is necessary to be familiar with the meaning of ostensive gestures and naming activities.

Additionally, "with different training the same ostensive teaching of these words would have effected a quite different understanding" (PI, §6). Think of the example of teaching the meaning of 'two':

> The definition of the number two, 'That is called two' – pointing to two nuts – is perfectly exact. – But how can two be defined like that? The person one gives the definition doesn't know what one wants to call 'two'; he will suppose that 'two' is the name given to this group of nuts! He may suppose this; but perhaps he does not. (PI, §28)

Hence, two individuals may participate in the same experience and understand it in a different manner. Words are not only representations of things, but assume the most different roles in the praxis of language. That is why their meanings do not rest on representations, but on the implicit normativity of language, which is connected to the way we act in different activities. The same word can be used in different manners, following different rules. Think of how differently we could teach a child to use the word 'water': to ask for water to drink, or to look at a body of water, or even as a signal that s/he needs help, for instance. A representation of the word 'water' would not be helpful to indicate how it should be used in connection to these practices.

For this reason, Wittgenstein frames language as 'the language-game', or a conjunction of language-games, a term created to highlight that "the speaking of a language is part of an activity, or of a form of life" (PI, §23). The meaning of words is not understood anymore as their reference, but as their use in language-games (PI, §43). What allows us to use the same word with different meanings is the family resemblance relationship, as with the resemblances and differences between the members of a family.

Wittgenstein's notions also have a family of meanings. Hence, the term language-game can be applied to primitive language-games, such as giving names to things; but also to more complex ones, such as reading, representing, doubting, formulating hypotheses, and criticizing; or be used in a more comprehensive manner, for understanding a style of thinking such as that found in mathematics.

The rules in which concepts and language-games are embedded constitute our understandings of them – in the same manner as the meaning of 'two' is connected to the certainty that it is a number and can be used to count. It is possible to have different degrees of understanding, in accordance with different purposes (PI, §29). If it is enough to know that the number 'two' means that group of nuts, then there is no need for knowing the concept of the number, but one does not go far with this type of learning. If the word 'two' is used to count, it is because we know that it is an allowed action within the language-games we learned involving numbers and counting. To only identify a reference for a word is not enough, we need to teach ways to use words within language-games, in which one learns about the normativity that is the condition which must be understood: "When one shews someone the king in chess and says: 'This is the king', this does not tell him the use of this piece – unless he already knows the rules of the game up to this last point: the shape of the king" (PI, §31). Hence, knowing the meaning of words requires the foreknowledge of the place in which they will be used (PI, §31) necessary to master a language-game. Language-games are constituted by a normativity, in Wittgenstein's words, a grammar,[5] of techniques, traditions, conventions, or rules that constitute the way we do things; these are not subject to analysis as to truth or falsehood, but are, rather, historically successful ways of doing things.

To learn a concept is to learn its normativity by using it in different language-games, in order to form a family resemblance relationship between the different uses. This will enable the recognition of a new language-game for its connections to what is already known. For instance, to learn the concept 'game', one learns to apply it to different games, such as basketball, chess, football, and so on. We form this concept after passing through a sufficient number of games to form the family resemblance relationships between them, thereby becoming able to recognize new games, even if they have not been seen before, or to create a new one. This is why only one application of a word is not enough to form a concept: because it would be like teaching someone what a 'game' is by showing them only the game of chess.

To understand a language-game is to understand a grammar. Two individuals can understand each other if they have the same linguistic background, the same picture of the world. The correct use of words,[6] made possible when one masters a grammar, is what constitutes understanding (PI, §199). Additionally, it is not possible to accept only one rule of our grammars, since they are connected to the others in a necessary manner. Hence, it is not possible to learn a language through only learning isolated applications of words, disconnected from the language-games from which they emerged. We cannot fall prey to dogmatic thinking and believe that concepts can be defined by a single precise rule, isolated from the others and from practices. For language to be autonomous, it is necessary to form family resemblance relationships between different uses of concepts and between different language-games, which will allow for new applications of words, new possibilities for following the rules of our grammars, and new ideas to surge.

As with words, the rules of our language-games cannot be learned separately from the games themselves. We could try to explain the normativity of language by explaining it with other words, by interpreting. However, "And what about the last definition in this chain?" (PI, §29). At some point, it will always be necessary to actually show how rules are followed in a language-game. For instance, we can explain what it means 'to walk', explaining that it is what we do to move, or that is when people place one leg in front of the other, but eventually we will have to show someone walking, since diverse understandings of the aforementioned definitions would always be possible. Obviously, when one has minimally mastered a language, it becomes possible to obtain some understandings by interpretations and explanations, but only if we have previously participated in language-games. For this reason, the conventions of language are not arbitrary, since they are connected to the way we live. In practice, the conventions of language do not determine action, but they do work as guides, for example, in showing where one should or should not go, as with traffic signs (Z,[7] §440).

Language is autonomous, and grammar is the condition for meaning, as it is not a candidate for being judged true or false. What is true or false is based on deeper agreements of language. For instance, the certainty that ‘all objects have extension’ is neither true or false, but an agreement implicit in our language-games: it is the way things work for us. This certainty is what allows one to say, “This table is two meters long”. The decisions of individuals are the fruit of reasoning within a style of thinking.

Because language is not only a tool for representation, but also constitutes its own thoughts and actions, we can acquire powerful abilities when we learn a new language. Consider how differently one may think when learning a new style of painting or a foreign language. This power of language is what can allow for freedom, since it allows access to dimensions never before explored. The formation of family resemblances enables us to be the authors of our own actions, ideas, and thoughts. Our concepts are not limited and new uses can be imagined.

THERAPY FOR THE PICTURE OF PHYSICS

In the field of physics teaching, we are used to textbooks, in which concepts have one single rule, usually of a mathematical nature. Physics knowledge is fixed – and all the subjectivity, problems, and hypotheses present in its process of construction are typically suppressed. However, physics language should not be considered as only comprising its formalizations:

> If concepts, transformed in the new theory that structures them, receive their physics meaning from relations in the theory (and, definitely, from the principles that regulate them), and if these relations are expressed through equations, it does not imply that the theory is reduced to the equations expressed therein. (Paty, 2001, p. 318)

There are a number of implicit certainties in physics language-games that relate the laws and concepts we are used to seeing in textbooks to the physical world and to subjective ways of understanding,[8] which can only be perceived when observing how physics language is used by physicists in their different activities.

Textbooks, as with science education research, usually take the formalized language-games of physics – in which concepts are used with formalized meanings, such as laws and equations, for purposes such as describing and predicting phenomena – as representative of physics knowledge. This picture is obviously correct, since various language-games in physics contain descriptions and predictions of phenomena. We need only recall mathematical physics, eclipse predictions, meteorology, econophysics, the building of dozens of precise experiments, or any number of other such constructs, to realize how this picture of physics is important to its language-games.

However, this picture is limited if generalized to everything we call physics language. We can imagine how physicist’s practices might unfold if they could only describe and predict phenomena from formalized theories. How would they know how to connect theories to the physical world, since mathematical abstractions do not correspond directly to reality? Certainly, there are other underlying assumptions besides those that explicitly compose a given theory. Otherwise, changes in physics knowledge would not be possible. Those who hold that experiments could be the sole source of change believe the impossible, since analyzing and building experiments involves questioning theories' foundations, an approach that is not possible when relying only on formalized theories. In order to indicate a more truly progressive course of practice, we shall here follow Wittgenstein's lesson and view language in a panoramic way, in order to see how physics language works. We are going to observe how physics concepts are used in the different language-games of classical mechanics.[9]

On the first level, the language of physics is connected to the physical world by different dimensions, such as acoustics, cosmology, gravitation, fluids, chaos, geophysics, environment, meteorology, ballistics, thermodynamics, and so on. From these observations, we can already appreciate that Newtonian mechanics goes far beyond describing and predicting velocities and accelerations of bodies in an empty universe. Theories are connected to the physical world. Physics has its own objects, made possible from its new language, which are not technological objects.

There are moments in which physicists theorize, share ideas with peers, write papers, participate in conferences, dialogue. We can further restrict the language-games and say that physicists criticize (data and theories), make hypotheses, make approximations, models, experiment (mentally and physically), question, try to solve theoretical and empirical problems, and so on. In the language-games of physics, we find certainties that indicate how we should know the world, what it means to exist, what reality is, and what theories, laws, principles, and methods are. At other times, physicists also analyze their own concepts.

The concept of induction, for instance, appears explicitly in Newton's work 'Optiks' (1706), and implicitly in his correspondences with Cotes (1713) and Oldenburg (1672) (McGrew, Alspector-Kelly, & Allhoff, 2009). Therefore, even as just demonstrated in this one example, physics language encompasses more concepts then those that appear in its formalized theories. However, based on our initial concern about the concepts that are explicit in theories, we will give them priority, in order to perform our therapy. It is important to mention that we consider epistemological concepts to be an essential complement to theories, rather than merely a subject for history and philosophy classes.

Physics concepts are constituted by a normativity that goes beyond their formalized rules, and can only be recognized when we see how they are used in the practice of physics language. There are rules from different dimensions, allowing the application of concepts in different language-games. Ernst Mach, criticizing Newtonian mechanics, writes:

> Let us now examine the point on which Newton, apparently with sound reasons, rested his distinctions of absolute and relative motion. If the earth is affected with an absolute rotation about its axis, centrifugal forces are set up in the earth: it assumes an oblate form, the acceleration of gravity is

> diminished at the equator, the plane of Foucault's pendulum rotates, and so on. All these phenomena disappear if the earth is at rest (…). This is, indeed, the case, if we start ab initio from the idea of absolute space. But if we take our stand on the basis of facts, we shall find we have knowledge only of relative spaces and motions. (1983, pp. 231–232)

In this criticism, we can observe that different rules are guiding the use of concepts, allowing their applications in different situations and for different actions. For instance, it is part of the concepts of 'motion', 'velocity' and 'acceleration', that they can be relative or absolute. These concepts are not only related to rates of change of mathematical quantities. It is part of 'centrifugal force' that it appears when a body is describing an accelerated and absolute motion in relation to absolute space. If Mach had considered only the concept of space as equated to that of distance, as we are used to learn (e.g. velocity as changes in space – distance – and time), he would not be able to make such objections. Mach was able to create a different application for the concept of space because he knew its normativity. On the other hand, hypotheses are also part of the normativity of concepts. Knowing the absolute space hypothesis as part of Newtonian mechanics, which is the privileged frame of reference for measuring the absolute motions represented by the three laws, allowed Mach to think critically – and to conceive a new hypothesis that could[10] give birth to a new theory.

Moreover, in Mach's criticism, it is implicit that we can only measure relative motion. This is a certainty physicists have; it is how things work in physics practices. Some empirical descriptions made possible within physics language-games also become part of its normativity, since it guides physicists' thoughts. Newton, in his notes about *The System of the World*, writes:

> As when as a stone is projected obliquely, that is, any way but in the perpendicular direction, the continual deflection thereof towards the earth from the right line in which it was projected is a proof of its gravitation to the earth, no less certain than its direct descent when suffered to fall freely from rest; so the deviation of bodies moving in free spaces from rectilinear paths and continual deflection therefrom towards any place, is a sure indication of the existence of some force which from all quarters impels those bodies toward that place. (McGrew, Alspector-Kelly, & Allhoff, 2009, p. 179)

The experimental result of the trajectory of a stone is part of the normativity of the concepts of gravity, motion, velocity, and force, since this observation justifies some of their applications. Newton talks about gravity not only as a downward force caused by the Earth or an acceleration calculated by the second law, but also as part of an attempt to explain the motions observed in nature, both in the heavens and in the Earth.

The concept of force is at the origin of changes in trajectories of bodies; force removes them from their inertial state. The many such facets of normativity are not always explicit when physicists use their concepts, especially if they are only using them to describe motions for a certain purpose. However, normativity nonetheless remains as part of all concepts and will appear when needed. Moreover, it allows for different actions. In this case, physics arguments – in favor of gravity and of certain properties of forces – were made possible. Changes in physicists' language-games serve to reveal how they know the normativity of the concepts they use. Therefore, teaching only the possible descriptions of this type of motion, disconnected to other rules that are part of the concepts themselves, is an activity which lacks a considerable amount of the information necessary for building a deep sense of the concepts in question.

Rules and concepts of a mathematical nature, which do not appear as part of the formalized theories, are also part of physics language, enabling different capabilities that go beyond descriptions and predictions. Concepts such as continuity, proportion, infinity, area, rates of change, stretch, or the circle, are also responsible for the meanings of physics concepts. Newton refutes the Cartesian theory of the gravitation of bodies in this manner:

> That forces should be directed to no body on which they physically depend, but to innumerable imaginary points in the axis of the earth, is an hypothesis too incongruous. It is more incongruous still that those forces should increase exactly in proportion of the distances from this axis; for this is an indication of an increase to immensity, or rather to infinity; whereas the forces of natural things commonly decrease in receding from the fountain from which they flow. (McGrew, Alspector-Kelly, & Allhoff, 2009, p. 180)

There are mathematical hypotheses about the behavior of objects in the physical world underlying Newton's refutation. In this sense, we could say that even the mathematical way of thinking is not adequate in textbooks, as well as in the image we have of physics knowledge, since both typically select only those mathematical concepts that are useful for making descriptions and predictions.

Historically-raised problems continue to partially constitute theories, working as part of their normativity. The laws formulated in Newtonian mechanics are answers to questions. The need to explain the appearance of centrifugal forces guided Newton's investigations (Ghins, 1991). This is what allows critical questioning, as in Einstein's introduction of special relativity in 1916[11]:

> I stand at the window of a railway carriage, which is travelling uniformly, and drop a stone on the embankment, without throwing it. Then, disregarding the influence of the air resistance, I see the stone descend in a straight line. A pedestrian who observes the misdeed from the footpath notices that the stone falls to earth in a parabolic curve. I now ask: Do the 'positions' traversed by stone lie 'in reality' on a straight line or on a parabola? (Einstein, 1999, p. 12)

Einstein begins his argument in favor of special relativity by analyzing the concepts of space and time in Newtonian mechanics, turning to the problem of explaining the true motion of bodies. Newton tried to answer the same question in his mechanics (Ghins, 1991). Einstein showed how it is possible to formulate a different answer to this question. Obviously, this question was not the only influence in the generation of special relativity, since there were other questions and assumptions, such as those related to the explanation of experimental results. However, it was an important part of Newtonian mechanics and retains its crucial meaning for special relativity.

Physics language becomes noticeably humanistic when we perceive that its products are answers to questions, and that these answers may change. If the choice for a frame of reference to measure motion were not part of the normativity of the concept of motion, it would not be possible to apply it in different contexts, to criticize it, or to make a new hypothesis. That is why the concept of motion is not only related to that of velocity. There are other underlying assumptions as well, as in any physics concept, and especially in those that are most fundamental to the discipline.

These rules that appear to not constitute formalized theories are part of them when physics language is being used in physics practices. This implicit normativity is the condition for meaning for concepts, their relations, principles, and laws – as connected in physics rationality (Paty, 2001). Together with theoretical abstractions, physics' normativity allows for different actions within physics thinking. In physics teaching and teacher training, a knowledge of this normativity emerges as essential, since teachers are the creators and enactors of teaching activities.

THE RELATIONSHIP BETWEEN PHYSICS THINKING AND PHILOSOPHICAL THINKING

First, it is important to note that the relationship presented here is one of the first order, in other words, philosophical thinking is part of physics thinking in its effort to understand the world. This is different from the philosophy of science, which is a second order study, and considers science as its object. Certainly, there are moments in which physicists philosophize in a second order mode (Serra, 2008), but this dimension is well known in science teaching. The first-order relationship is expressed by the need for a connection between the high abstract formalizations of theories and the physical world, in which there is a tension between the formal and empirical dimensions:

> On the one hand, the theory, in the axiomatic transparency of its statements, would give its own meanings (in other words, its content, in this case, physical content). On the other hand, if the content has nature as its object (in our case, the reality of physics), it is connected to experience (therefore, it can be called empirical), and cannot be reported only by its formal structure. The statements of a theoretical science imply, therefore, a tension between the formal character of theories and their contents, referring to the need for reality. (Paty, 1992, p. 107)

This tension is overcome by the constructions of meaning within physics language-games. The physicist, trying to understand observations and phenomena, will restructure concepts and give new meanings to words, constantly re-elaborating the old ones. At this moment, s/he will also work on the enunciation of meanings – which is when we realize the ways in which they were already part of theories. Moreover, our first interpretations of the physical world are made from a minimum degree of conceptualization, and, therefore, themselves contain meanings. These meanings compose theories in their relations to the world, since they bring in themselves the need for their own interpretations (Paty, 1993, p. 103). Hence, the construction of meanings is not left to philosophers of science, who have the role of unveiling, but not constructing, meaning.

The need for meaning connects physics thinking to philosophical thinking, creating rules of a philosophical nature as part of the normativity of physics. Philosophy also provides physics with a critical style of thinking, by making available techniques for the clarification and organization of concepts. These rules can have a metaphysical nature, such as those related to the structure of space and time and the composition of matter, or an epistemological one, related to concepts such as laws, principles, causality, and induction.

In times of crisis, it is common to consider philosophy as part of physics, since physics performs the typical philosophical activity of clarifying concepts. This reflects the critical dimension of theories, without which physics rationality does not exist (Costa, 1997). At such moments, physicists need to clarify the assumptions of theories and search for new answers to old questions, or try to develop new questions and new meanings. However, in order for this critical activity to be possible, it is necessary for these expectations to already be part of theories, pertaining to their own language. Among them will be those of a philosophical nature, bringing philosophical problems and hypotheses that make it possible to connect theories to the physical world. Theoretical constructs cannot all be verified by experience, but we can interpret phenomena and physical properties as a whole (Paty, 1992).

Answers to problems of a philosophical nature, which cannot be verified by experience but only justified by a chain of reasons, inherently bear certain limitations, making it possible to arrive at different answers and, thus, holding great importance in the construction of new ideas. Here is the site where criticism may thrive. At the same time, the philosophical character of physics is also its strength:

> In the hands of such physicists as Helmholtz, Boltzmann and Hertz, philosophy was used as an instrument to ensure and expand the autonomy of science. In other words, science is capable of choosing its problems, the methods for solving them and the criteria for recognizing suitable solutions. (Videira, 2013, p. 12)

The philosophical dimension provides intellectual autonomy to physics, allowing for the existence of a new field of action, which is less constrained than those used in experiments and mathematics. By means of (non-isolated) philosophical rules, criticism, the construction of physics meanings, the clarification of concepts, and the formulation of hypotheses are all possible. The application of words in physics language will also take into account its philosophical rules. The certainty of a statement such as ‘absolute motion is the translation of a body from one absolute place to another' will indicate how we use words such as motion, change, place, space, and so on, within classical mechanics.

To say that philosophy is part of physics rationality does not mean that it will be present in all physics language-games. Philosophy is part of the normativity of physics, particularly regarding its more fundamental concepts. However, there are cases in which physics knowledge will have only mathematical meanings. What will show the pertinence of such knowledge to physics is its family resemblance relationship with other language-games. Although there are games in which criticism plays a lesser role, as in the case of mathematical physics, these games will certainly be connected to language-games with philosophical dimensions, since physics needs to refer to the world.

TEACHING A NEW STYLE OF THINKING: USING NORMATIVITY TO TEACH NEWTONIAN MECHANICS

How might we teach physics language in a more humanist manner? First, we should consider the need for knowledge to be taught in connection with its normativity. This process can only be effective when language is working, so we will be including the subject as the author of different language-games. We are forced to leave behind the old view of physics language as facts, descriptions, and rules about the world, and to instead be concerned with its connections to actions. We will be responsible for teaching the normativity of physics, via including students in physics language-games and allowing them to think and act in new and different ways only imaginable within the possibilities offered by the language of physics.

The human dimension of physics knowledge can be effectively represented by including philosophical assumptions together with those of empirical and mathematical natures,[12] offering students access to the history that persists as part of theories. When we present philosophical hypotheses and problems, we are considering physics knowledge, in fact, in its tentative and changing character. Knowing the normativity of physics allows for the emergence of a new autonomous field of action, which does not determine thinking[13] but functions as a guide. Moreover, problems and hypothesis of other types can also be presented as part of philosophical thinking, where useful in enunciating and creating physics meanings, as we have discussed.

We are going to present a humanist model for teaching the Newtonian school of thought, based on our experience with high school and pre-service teachers. This model will consider which should be the most fundamental aspects of normativity to be taught in classical mechanics in order to lose neither its humanist features nor its connections to experience and mathematics, although we give priority to the philosophical dimension. We do not believe in proposals that determine teacher's actions, but in building models of normativity that can allow them to choose different paths.

This model draws upon an analysis of the metaphysical hypotheses and problems[14] that appeared in the construction of Newtonian mechanics, supported by the philosophers Michel Ghins (1991) and Eduardo Barra (1993). In this historical episode, Newton was trying to explain the appearance of centrifugal forces and searching for a frame of reference, which led him to propose his absolute space hypothesis. It should be stressed that this analysis served to recognize the normativity of the concepts involved, which is an exercise that teachers should do themselves in the classroom context. In the latter, the teaching of normativity will not occur within the way of thinking of philosophers or historians of science, but through inserting students in physics language-games in which they can follow these rules.[15] Our purpose is not to teach students a philosophical way of thinking, but a physics one.

First, the intention of Newtonian mechanics is to understand the movements observed in nature – and this should be conveyed to students in some way. The need for understanding motion is not self-evident – why did physicists choose motion as their main concern in classical mechanics? When teachers start mechanics classes by talking about the rates of change of movements and their relation to distance and velocity, they are skipping an important aspect of classical mechanics which can influence students to start thinking about the world from the point of view of movement. The assumption of the importance of movement for understanding nature seems to be obvious, but it is not so for all students. Likewise, the importance of mathematical abstractions is not self-evident. Hence, a discussion about these intentions and assumptions is important, leading students to observe that motion can be found in every phenomenon observed in nature, and to realize that pondering and understanding motion is thus of real value.

Physicists desire to understand the movement of the Sun, planets, and bodies on the Earth. To speak of motion, its representation is required. However, such representation is the fruit of successive mathematical abstractions of the natural world; we are used to these abstractions and able to make sense of them, but students are not. In our educative experiences, asking students about their knowledge of motion has produced positive results. Interacting with the teacher, students can deduce common properties of the different types of familiar motions. It is always important to remember that the teacher must not expect students to discover all the known abstractions constructed in physics history. At some point, teachers will have to tell their students about the conventions used for analyzing motion. It is, however, imperative to give students opportunities to think for themselves within the new style of thinking provided by physics, guided by their teachers, who will already be speaking from a particular language-game and from implicit certainties. This should be viewed as a change (not elimination) of language-games, from those of students' everyday lives to those of physics. The teacher will invite them to change the frame of reference through which they are used to seeing the world.

A second important abstraction in Newtonian mechanics is the inertial and non-inertial classification of motions. For the philosophical dimension of this theorization, mental experiments could be used,[16] such as Galileo's inclined plane and Giordano Bruno's[17] idea of throwing an object up on a moving boat. For the empirical dimension, observing motions in which is possible to perceive the effects of inertial forces is important; teachers might include explorations of circular motion, in which centrifugal force is observed, and of accelerated motion, in which there are other types of inertial force, in classroom activities.

It is essential to highlight the differences between motions. Physicists explain such differences by considering one property as natural and describing all variations using the natural property as a reference (Toulmin, 1953). In Newtonian mechanics, inertial motion is natural and Newton's second and third laws explain its variations. Two observers may have different conclusions regarding the trajectories and velocities of objects. Showing the existence of circular motions in which there is no centrifugal force is also important. Take, for instance, the case of a body B rotating around a body A at rest:

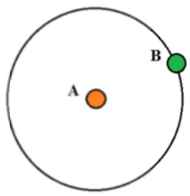

Figure 1. A body B rotates around a body A at rest

From A's reference frame, B describes a circular motion in which centrifugal forces appear, but from B's, A describes a circular motion without centrifugal forces. It should be noted that the concepts of rest and referential frame are not self-evident and also need elucidation. In our work with students, we always discuss the need for a material and visible frame of reference to measure and perceive any type of motion, since students usually believe that it is possible to observe motions in themselves, independent of any referential frame (Rocha, 2015).

Questions that emerge from these differences include: 'Why do these motions happen?' 'Why can we observe centrifugal forces in some motions but not in others?' 'Why do observers in different frames of reference see different motions?' It is usually easier to start from the second question, since the first requires previous knowledge of Newtonian mechanics. The second question leads some students to argue for the existence of true motion, while others argue for the notion that any observer should have the right to observe true motion, which leads to the question, 'Is there any true motion after all?' (Which is, in fact, a question that Newton also wished to answer!) Alternatively, is any frame of reference valid and any observed trajectory of a body equivalent to the others? Here, a discussion emerges about relative and absolute motion, and whether space is independent of bodies or a relation between them.

Once students have understood these problems, which will lead them to think within the mechanical style of thinking, the teacher can then present Newton's arguments and answers. Newton argues via the difference between inertial and non-inertial motions. In the case of body B rotating around body A,[18] Newton interpreted B's motion as true, since in this case the centrifugal force appears, while in A's motion this force does not exist. Newton could have chosen A's motion as true (by the way, this is a common issue for students). However, he chose B because it can also explain why centrifugal forces appear.

For Newton, inertial motion would be that existing naturally, without the need of forces. When some force tries to move a body from its natural state, centrifugal forces appear as an attempt to avoid that force. That is why B's motion is true, since B's true acceleration would have generated a surge of centrifugal force. A's circular motion, viewed from B, is not true, since no centrifugal force appears – indicating an inertial state of motion. Therefore, there are two classes of true motions, inertial and non-inertial (in which inertial forces appear). Accelerated motion in which there is no inertial force is considered an illusion.

From this classification, the remaining question is to determine the frame of reference, since this is necessary for measuring motions. Students often indicate A as this referential, but when we ask from which frame of reference we could know A's motion, they answer that a third frame of reference is necessary, and so on. They often compare this situation with the Earth rotating around the Sun, and the Sun rotating around our galaxy, etc. If no material body can be chosen as the privileged frame of reference, what can we do? Students usually make the most interesting proposals in trying to answer this question, some of them very similar to those made by Ernst Mach, who proposed the center of mass of all bodies in the universe as the frame of reference (Rocha, 2015).

Newton proposes choosing absolute space as the privileged frame of reference, defining true motions as changings of place in this space. This decision is due to the need for choosing a frame of reference that is not material and is external to matter; absolute space, as independent of matter, immovable, and present in all places, fits these requirements for the privileged frame of reference. Students often question this hypothesis. At the same time that they find it unbelievable, students recognize it as the best way to solve the problems posed to them, given the knowledge and tools available.

However, if we recall that we can only detect and measure motion from a certain frame of reference, how can we measure motion in relation to invisible, homogeneous absolute space? For Newton, it was enough to choose bodies at rest in relation to this space (this is also a common proposal among students), since, from there, we could observe the same motions as if we were in absolute space – these are the well-known inertial frames. At this point, students usually become curious about the impossibility of differentiating between rest and rectilinear and uniform motion. This is precisely one of those limitations of Newtonian mechanics which opened a field to posterior criticism in the history of physics (Ghins, 1991). Students usually discuss this limitation and try to think of alternatives. At this moment, the teacher can connect the conversation with some of the criticisms levelled against Newton by his successors. For this reason, inertial frames of reference must include rectilinear and uniform movements in relation to absolute space. Only from them is it possible to observe true motions.

Students usually question the existence of inertial frames of reference, since all bodies in the universe are under the influences of, at the very least, gravitational force. Here is when the necessary approximations of the theory appear. Newtonian mechanics are valid when we can abstract from the outside world and consider a body on Earth at rest in relation to absolute space (in that sense taking the Earth as absolute space – and disregarding its motion around the Sun). This consideration is useful for the study of bodies on Earth without significant displacements. For studies on a larger scale, this approximation is not enough, as when planets are studied, in which case the Sun usually is a good referential.

In summary, Newton's three laws are connected in a system. The first tells us what natural motions in the universe are like when there is no interaction with other bodies. This motion depends solely on the shape of space (Euclidian geometry). In this case, the only possibilities are to be at rest or in rectilinear and uniform motion in relation to absolute space. What it means to be in relation to absolute space is crucial to understanding the meaning of inertial motion. It is helpful to extrapolate this knowledge to common situations familiar to students, such as the movement of a person in a decelerating bus, which approximates the Earth as absolute space. This is important in order to avoid distorting the meaning of inertia. Without these considerations, it might seem that any rectilinear motion, observed from any frame of reference, is inertial, which substantially distorts its meaning.

The second law, which benefitted from the observations of many earlier scientists, relates force, mass, and acceleration, indicating how a body may be removed from its inertial state. Force is needed to accelerate the body, the impact of which will depend on the body's inertial mass (which is different from gravitational mass). A body without mass, and, hence, without inertia, would be infinitely accelerated. Newton's second law gives us a tool to explain why a body was removed from its inertial state. At this point, connections with the mathematical dimension of the concepts of velocity, acceleration and force are required. Newton's third law describes the consequences of removing a body from its inertial state: inertial forces will appear (reaction), a phenomenon for which absolute space is responsible. When an inertial force appears, we then realize that we are not in an inertial frame. Understanding inertial forces is crucial to understanding Newtonian thought. From them, it is possible to justify the adoption of the concepts of inertial frames of reference and absolute space.

Teachers can follow this normativity through different strategies and themes. For instance, the Newtonian style of thinking can emerge from a discussion about the motion of planets and other celestial bodies (centrifugal force is responsible for the oval shape of earth) – in this case, students should have previous knowledge of these facts. Different thought experiments, activities, observations, experiments, and exercises can be included in order to teach the above-mentioned abstractions and assumptions of Newtonian mechanics. Teaching this philosophical dimension will allow the emergence of questions, hypotheses, and criticism, just as was the case over the course of the history of physics – for instance, where the ether hypothesis was proposed as a substitute for absolute space in electromagnetic theory, and to allow new ways to answer this question in relativity theory. Although we have focused on the philosophical dimension, this normativity is stronger when considered together with its related mathematical and empirical aspects.

FINAL CONSIDERATIONS

We have shown how the current picture of physics knowledge is equated to that presented in its formalized theories and based on an ingenious view of the way language works. We have demonstrated how this conception, which tends toward utilitarianism, is not compatible with humanistic claims, even if educative proposals are accompanied by humanistic intentions. We have argued, from Wittgenstein's philosophy of language, for a consideration of how language works when used by physicists in their practices, and concluded that physics language is not only a tool for communication and representation, but constitutes forms of life. Hence, physics knowledge cannot be conceived in a predominantly utilitarian manner if we want to offer students a humanistic education. Physics language can provide new possibilities for knowing, thinking, and acting, which are only achieved if we go beyond its utilitarian use.

The concepts presented in formalized theories are connected to the normativity of physics practices, encompassing more rules than those presented in the final theory as we see it in textbooks. We have argued for a consideration of the philosophical dimension of this normativity as a way to bring a more humanistic approach to physics knowledge, and proposed an example within Newtonian mechanics. We contend that it is not enough to know 'that', but that students should also learn 'how'. In other words, it is not enough to teach students that physics is a human endeavor via the insertion of history and philosophy of science in science teaching, teachers must also learn to teach ways of thinking about physics in a humanist manner. Students should learn this way of thinking using the new language of physics.

Naturally, a utilitarian use of physics concepts can help students to understand devices and objects such as cellular phones, electricity bills, or hydroelectric plants; these are all important things to comprehend in our current social contexts, and will enable some actions and activities. However, the scientific rationality present in our society is more deeply entrenched than such a treatment of physics can elucidate. Moreover, the meaning of concepts will depend on the normativity of which they are part. We cannot teach all possible applications of physics concepts, but we can teach students their normativity, which grants students precious and crucial autonomy of thought. If all applications of concepts in a physics curriculum are previously determined, the teacher loses her/his authority and identity (Young, 2010). Utilitarian uses of concepts cannot overcome everyday experience – they are more useful as local tools we can offer to students, which may easily be incorporated into their conventional ways of thinking.

Scientism is the most pervasive influence of the scientific way of thinking in our society, spreading the ideology of the natural sciences as the only and correct way of knowing. This ideology is mainly based on the power of predicting and describing phenomena through its mathematical dimension. People, cultures, and ethnicities are reduced to numbers, laws, and reports. Learning the style of physics thinking we have proposed allows students to perceive how, when, and why this thinking is efficient, and to realize its abstractions, limitations, and intentions, as well as its historical character. Hence, we can avoid generalizations to fields that are not compatible with physics' intentions. In addition to understanding the scope of physics knowledge, we can offer students a new picture of the world, allowing them to develop both intellectually, through new learning experiences and language-games, and in their identities, for having taken a role in the shared development of physics knowledge. The power of learning physics resides precisely in learning its way of thinking.

NOTES

[1] The term 'picture of the world' is used in a Wittgensteinian sense, as the end of our reason chain, directing our thoughts in one direction. "It is like a pair of glasses on our nose through which we see whatever we look at. It never occurs to us to take them off" (PI, §103).

[2] In this work, we are going to give examples from Newtonian mechanics, in order to facilitate comparisons, since we are going to build a proposal for the teaching of this theory.

[3] See Lederman et al. (2002, p. 499). In this publication, the authors present a consensus list of knowledge about the nature of science which is gleaned from the consensus from international standard documents. This view is well known and used in science education research.

[4] As demonstrated in a recent review by Teixeira, Greca, and Freire Jr. (2012).

[5] Not to be confused with the use of the word grammar related to the structure of sentences.

[6] There are degrees of correctness.

[7] Zettel, published in 1967.

[8] Paty (2001) demonstrates the necessary relationship between both the subjective and the objective dimensions in physics theories.

[9] We could analyze other types of language-games, with an even more panoramic view. However, we want to emphasize physics language as related to theories, since it seems difficult to see how they are embedded in physics practices; showing this can also allow for different abilities when we consider how they are used.

[10] Mach had not finished his new mechanics, but nonetheless significantly influenced Albert Einstein (see Fitas, 2009).

[11] We consider Einstein's analysis as, in a sense, part of Newtonian mechanics, because this theory contains its own prospects for criticism.

[12] Hacking (2012) argues for the existence of different styles of thinking in science, and the three mentioned here can be framed to represent what he calls the laboratory, hypothetical modeling, and mathematical styles.

[13] This is different from teaching students how to apply concepts in particular situations external to physics practices. These applications are learned in a very determined way (e.g. learning how to calculate the electric resistance of the shower in order to know how much of the electric bill is for the shower). This is a necessary facet of understanding, but to understand the concept only from a particular application is to determine thinking,

[14] We prioritize metaphysical assumptions within the variety of philosophical ones. In a broader study, it would be interesting to analyze assumptions of an epistemological nature, such as the notion of causality embedded in Newtonian mechanics.

[15] Historical episodes should be taken into account in planning educative proposals, helping teachers to identify the normativity surrounding concepts.

[16] The fact that something has been approached in a certain way historically does not mean that it should be approached in the same way in the classroom. It is not necessary to perform the same analysis as a historian would, since this mode can be left to a separate discipline involving the history of science. First, students need to understand these problems and then be encouraged to learn how to think about them in new ways.

[17] To see examples of mental experiments, see Gilbert and Reiner (2010).

[18] Newton presents another mental experiment. See Ghins (1991).

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Maristela do Nascimento Rocha
Post Graduate Program in Science Education
University of São Paulo
São Paulo-SP, Brazil

Ivã Gurgel
Department of Experimental Physics
Institute of Physics
University of São Paulo
São Paulo-SP, Brazil