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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

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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 10th-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