A PROJECT TO UPDATE THE PHYSICS CURRICULUM IN THE SECONDARY SCHOOL IN BRAZIL

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ABSTRACT

The Physics normally taught in Brazilian Secondary Schools has been limited to addressing classical contents (from the18th and 19th centuries). The updating of the educational syllabus has been sought as a necessity in order to put the students in touch with the recent knowledge produced by 20th century science. Since 2003, a project favorable to updating the curriculum of Physics is under development at the Faculty of Education of the University of São Paulo in association with the Secretariat of Education of the State of São Paulo. Many pedagogical contents were prepared and evaluated that will deal with the needs of the public schools. During that period the following courses were developed and applied in the schools:

- a modulus of foundations of Quantum Mechanics (4 years);
- a modulus of Physics of Elementary Particles (3years);
- a modulus in Relativity (first year).

KEYWORDS
Modern physics, curriculum design, didactical transposition

1 - INTRODUCTION

The present text presents a pedagogical experience held by a research/intervention group that involved both Brazilian Universities and schools. The current research faced a challenge: to convey the **updating of part** of the Physics curriculum in secondary public schools in São Paulo State by introducing some topics of the Modern Theories, as Quantum theory, Elementary Particles and Special Theory of Relativity. The group is composed of professors and ongoing post-graduate students at the Faculty of Education in the University of São Paulo, and teachers from public schools in São Paulo State, Brazil. The current research team shares responsibilities in elaborating, applying and assessing the teaching proposal. “Fundação de Amparo à Pesquisa do Estado de São Paulo” (FAPESP)[1] provided financial support and necessary resources/conditions to the Physics teachers in the team. Such support was crucial for the successful teaching experience reported below.

[1] FAPESP is the financial supporting agency that sponsored the current research.

There has been a lot of talk about the need for innovation in the teaching of Physics at the secondary level[2], although there is little material presenting clear, objective and practical proposals for teachers (Gil et alii. 1987, 1988; Barojas, 1988). Teachers usually have little (or no) time to dedicate to study/research on teaching strategies that can prove to be effective in changing their traditional practices. Moreover, they face great difficulties in applying proposals that have been engendered within universities and research centers, given that the latter ones are distant from real classroom situations. Consequently, educational innovations often remain distant from schools and find no opportunity to be evaluated in practical situations.

The last century, though, witnessed a greater amount of innovations and theoretical breakthroughs than at any other historical period. The range of knowledge within both microscopic and macroscopic perspectives in Physics has been enlarged as a consequence of disrupting classic concepts and meanings. Theories such as the General and Restrict Relativity and Quantum Mechanics have been used as ground-work for the production of knowledge in a new technical and scientific panorama. The world as perceived today is significantly different from the world of some past decades because science and technology have modified the social environment. Thus, comprehending routine life without specialized knowledge is impossible. It is indispensable to incorporate modern and scientific knowledge so that the world around us is fully understood.

Contemporaneous and Modern Physics strongly penetrates our current society. Students make part of such a routine, which is modified by science and technology and take advantage of it as they face science names and figures that are conveyed by the media. Science fiction stimulates teenagers' imagination – and also those who are no longer teenagers– by inciting the search for new, virtual or extraordinary facts.

PAULO (1997) reports the influence of such scientific knowledge that is present in every-day life by showing teenagers the existence of alternative conceptions on some subjects of Modern Physics. The author claims that the production of such alternative conceptions originates from the interaction of the student with the science-modified world. Results such as these have suggested that students with scientific knowledge obtained/built from ordinary life, where they perform as active citizens, can be found in many classrooms. Consequently, physics teachers tend to find it difficult to deal with such students, for teachers have only classic knowledge at hand.

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[2] Brazilian school system comprises of two cycles: elementary (1st to 8th grades, in two distinct cycles) and secondary (1st to 3rd grades). The latter would resemble the American standard High School system.

This scenario reinforces the need of a curricular updating that could deal with students who cannot recognize the meaning of the traditional content taught at schools in their lives (Gil and Solbes, 1993; Fischler and Lichtfeldt, 1991 and 1992; Cuppari et alii, 1997). Therefore, the teaching of Physics at schools should be considered as a basic element for comprehension and inclusion in today's world, for understanding the modern world and for the cultural satisfaction of today's citizens.

Schools in Brazil have not reached the point of appropriately handling the knowledge originated in modern and contemporaneous theories. Traditionally, Physics in the Brazilian secondary school system has limited its access to theories from 17th-19th centuries. Summaries in didactic books or course programs follow the historical development phases: students invariably start their studies with Kinematics (end of the 17th century), go on to Dynamics, Hydrostatics, Thermology (18th century) and reach Thermodynamics and Electromagnetism (19th century) only at the final stage. Such curricular organization reflects a hierarchical and linear conceptual structure that considers the historically "older" facts as pedagogically preliminary. The implication here is that students must go through the historical path of knowledge. Within such perspective, students can only learn about the electromagnetic field (that is taught during the third year of secondary school) if they have already learned about Newtonian Laws (that are taught in the first year).

Such a way of considering the curriculum has prevented teaching from going beyond the borderline of the so-called classic theories (produced up to the 19th century), once the short three-year period at the secondary school is not sufficient to engulf the long scientific path of the physical science. The students' notion of Physics does not match the true scientific nature. Physics School, restricted to classic knowledge, thwarts the understanding of what research activities are currently conducted at university centers and laboratories.

Several Brazilian official documents show the need for updating the Physics programs. The following paragraph can be found in the *National Curricular Parameters* (NCP):

> To the current merely propaedeutic secondary level, scientific matters such as Physics have **omitted developments carried out throughout the 20th century** and presented traditional topics in an encyclopedic and excessively deductive manner. To the kind of education that is aimed at reaching, only a **permanent review** of what will be taught within each matter will grant **updating with the improvement of scientific knowledge**, and partly with its technologic incorporation. (page 8, bold types emphasized by authors. *NCP (2000) Secondary School*[3]

[3] Part III, page 8.

Such lack of tracking between school knowledge and skilled knowledge has been widely pointed out in researches on the teaching of Sciences.

Brazilian researchers have tried to encourage a deeper analysis on the difficulty of producing a curricular updating in Sciences. TERRAZAN (1994) analyzes the educational panorama[4] and focuses on the needs to insert Modern Physics in secondary schools. He comes up with a pedagogical proposal guided by the image of knowledge as a three-dimensional, meaningful web that counteracts the current panorama, based upon a linear teaching concept and settled within an empirical view.

PEREIRA (1997) agrees with the fact that the contemporaneous world is highly technological and that its comprehension must originate in schools, mainly from the programs within Natural and Social Sciences, Physics, Chemistry and Biology, so that relevant subjects can be included in the curriculum of an open minded individual who understands the surrounding environment. A person who can make his own decisions and play his social and economic roles according to the current historical period.

VALADARES & MOREIRA (1998) defend the idea that secondary-school students should know the basics of today's technology, once it directly impacts their lives and can possibly define their professional future.

The scientific-technological dimension of modern society is not the only argumentative condition for discussing the introduction of CMF. The cultural dimension of Physics is also taken into account in such curricular updating, for the scientific spreading has prompted the inclusion of scientific aspects as objects of the modern western culture.

Zanetic (1989) focuses on the importance of Physics in secondary schools:

> *the development of Physics is an integrating part of the social history, it is a social life product, for it brings in a huge range of factors and interests that are changing depending upon the time during which certain theories and concepts about the world had been developed.*[5]

[4] Despite the changes that have occurred in the national education panorama since 1994, the focused topics in the present work have not been significantly changed to invalidate our review.

[5] ZANETIC (1989), p. 22.

The need to grant citizens dominion on scientific-technological artifacts of routine life — material, cultural, concrete or virtual artifacts — leads to a curricular updating that could grant success to actual topics within modern physical theories that have been developed throughout the 20th century.

"Thus, we can find many justifiable things in literature that allow us to set the following hypothesis: there is a national and international tendency to update the curricula in Physics and many substantiate arguments exist for that". (Ostermann and Moreira, 2001).

Research on modern physics content

The need to introduce CMF into Physics teaching can be considered a consensual fact within the context of educational research. However, the same cannot be said when teaching strategies are considered. The answer given to "Why?" is obsolete, but the answer given to "How?" is found in recent research.

Some researchers have tried to evaluate teaching strategies regarding modern and contemporaneous contents within the Basic Education, with published preliminary results. Ostermann et al. (1999) describe the process of introducing and analyzing a contemporaneous physical topic – elementary particles and fundamental interactions – at a school in a southern city in Brazil, Porto Alegre. They describe the period in which the topic was applied at school and the obtained results, and ultimately they arrived at the conclusion that it is necessary to invest on the **teachers' background**. COSTA & SANTOS (1999A) work on teachers' continuous background in a southwestern city in Brazil, Rio de Janeiro, and practically reached the same results. They claim it is necessary to overcome both the lack of secondary-school teachers' background and the scarcity of materials related to CMF. These authors suggest that teachers should exploit routine artifacts so that other themes such as laser, holograph, chaos and fractals, relativity and radiation could be developed *a posteriori*.

CAVALCANTI (1999) makes use of the media to present the theme Cosmic Beams through a historical approach on the evolution of ideas and experiments in Physics. PINTO, A.C. and ZANETIC, J. (1999) study the development of secondary-level teaching materials related to Quantum Physics. He points out certain difficulties that appear when this topic is taught, such as the mathematical formalism, focusing on the need for a less formal and more qualitative teaching, and suggests that this could be "overcome" by making use of the History of Science. ARRUDA and VILLANI (1998) have developed a project that attempts to elaborate proposals of inserting CMF into the curriculum of Physics in Parana State, Brazil; such project involves professors of the Physics Department of a southern city university in Brazil, Londrina State University, and secondary school teachers.

The results that have been presented until the present time do not lead to an efficient teaching model that could transpose CMF topics into secondary schools, despite the fact that numerous researches have been published on the subject. According to Ostermann and Moreira, "...the number of published works that focus on the problem by considering the teaching point of view is still small, and even smaller is the number of those that have tried to place updating proposals in the dassroom" (Ostermann and Moreira, 2001).

The lack of criteria to produce school knowledge in CMF topics can be pointed as one of the major factors that limit physical curricula to classic content. Zanetic's impending phrase, then, can be real: we should "teach the Physics of the 20th century before it is gone" (apud Terrazzan, 1992). The 20th century is gone and students are still forced to get along and move forward with the teaching of Physics that goes no further than the one from the 19th century.

Theoretical approach and Methodological Resources

Normally, Physics courses at secondary level are generally very traditional and with few open doors for innovation. Topics were placed in curricula and didactic books several decades ago; teachers fully know the sequence of didactic activities and quite frequently do not feel at home when changes are proposed. Most of the teaching material that is available to students fits conditions established for the traditional teaching, where topics from the Classical Physics still predominate. Although Physics teachers keep a contact with the content of both Modern and Contemporary Physics, they feel comfortable teaching the very same Physics that they learned when they studied at High School. Thus, Classical Physics is seen as the "natural" content to be taught (Carvalho, A. M. P., Garrido, E., Castro R.S. 1995).

Since the beginning, the internal-team dynamics had been focused on the topic definition and structural classroom activity with the objective of settling a teaching sequence that could allow secondary level students to reach both Modern and Contemporary theories. There is a great amount of topics that might potentially be taken into consideration, when attempts to insert Contemporary & Modern Physics into the Basic School curricula are proposed. From Bohr's atom to the *Big Bang*, from time-space Relativity to the Chaos Theory, all of these are knowledge factors that were produced throughout the 20th century and in some way clash with the classic shapes of conceiving the physical world. The point is not that CMF as a whole should find room in secondary school curricula, for classic theories should certainly be an important part of it. The question is about the selection of topics that might be transposed, and such selection would be based, on one side, upon internal criteria to Physics itself as a scientific area, and on the other side, upon internal criteria to schools and their role in society.

We found a research in literature (OSTERMANN et al. 1998) on the selection of CMF subjects based on a survey with Brazilian professors and researchers in Physics. By making use of the Delphi approach, the surveyed individuals were asked about which topics in contemporaneous Physics should be introduced into the secondary school curriculum. Suggested CMF topics were Quantum Mechanics (63%), Restrict Relativity (50%), Solid State (40%) and Particle Physics (38%).

This survey points out that the topics on quantum theory, as it seems natural, should be put in first place in the curricular updating of Physics for the secondary school. Lawrence (1996), Cuppari et al. (1997), Pinto and Zanetic (1999) describe indoor experiences toward the introduction of Quantum Mechanics topics in the secondary level. Greca, I. and Freire Jr., O. (2003) and Freire et al. (1995) discuss the introduction of this topic in the secondary school by approaching historical and epistemological aspects of the topic and its relationship with learning-teaching processes. Such works emphasize difficulties in teaching the aspects of the quantum theory to young students. However, all authors show an optimistic view for successful possibilities.

The current research considered such difficulties and attempted to present solutions by conducting an action-research focused on pilot-courses of modern physics for secondary level. The members of this group were transient along the two-year activity period but usually remained as follows: the team coordinator, who is a professor at the Education College and researcher on the teaching of Physics, six Physics teachers who work at secondary-level public schools in São Paulo, one Master's degree student in the area of the Physics teaching and one graduate student in Physics. To these permanent team members, temporary support people were added and they included researchers in Physics at the Physics Institute (University of São Paulo) and various graduate and post-graduate students.

The analysis of the issues of these pilot-courses lay on "Didactical Transposition" (Chevallard, 1991). This theoretical approach considers three steps of scholar knowledge: *Scientific knowledge* ("savoir savant" in French), *knowledge-to-be-taught*, and *taught knowledge*. The noosphere is the domain responsible for driving the epistemological path from scientific practices to didactic system.

Chevallard attempts that the didactical transposition is for the teacher

> [...] a tool that allows revised, take away, to question
> evidences, doubt about the simple ideas, abandon
> familiarity, hence misleading its object of study. In a word, is what enables
> exercising its epistemological surveillance. (CHEVALLARD, 1991, p.16)

It is exactly the capacity of questioning the adequacy of knowledge for a didactical system that will supply indications to accomplish the curricular update. In Chevallard words:

> "… we must in principle abstain from teaching subjects, including the "interesting ones" (since it is the point of view of the professor), for which it would not be made use of a satisfactor" (CHEVALLARD, 1991, p.54)

The teachability will eventually depend on three main factors, which must in turn be assessed in relation to the social organization and cultural values. Firstly, their *social value*, or *epistemological relevance* – which essentially accounts for the fact that bricklaying, for example, or even taxidermy, are teachable. Secondly, their *cultural relevance*, which measures their cultural "desirability". Thirdly, the *degree of exposure to society* of both the teaching practice and the corresponding school-free social practice. (Chevalard, 1987)

Results and Analysis

We have produced three courses that focus on the following subjects: basic quantum mechanics (particle-wave duality), physical particles and special relativity. The first two are implemented more than twice. The last one was implemented only once, in 2007.

Teaching strategies were produced from former pedagogic experiences and developed by the same team in another project[6], and can be summarized as follows:

a) Historical and epistemological *Approach:*

b) *Use* of demonstration-investigation experiences[7]

c) Use of the *Open Laboratory*[8]

d) *Use* of open questions and problems[9]

e) *Use* of alternative bibliographical references for classroom *(Support texts):*

f) *Use* of videos*:*

g) *Use* of the Internet and software:

h) *Use* of analogies and metaphors[10]

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[6] A project that was formerly elaborated under the topic "Thermodynamics".
[7] these are **demonstrations** for they are conveyed by the teacher and observed by students, but are also **investigative** for they are not used to illustrate, but to make students think over a certain subject and what he sees, and try to find explanations in the theoretical model. Alonso, Sanchez et al. 1992.
[8] this is a kind of laboratory in which students actively participate with teachers in every step, from hypothesis to conclusion elaboration.
[9] these are questions for group discussion, new situations are presented and the group of students can discuss and present their answers based on the explained theory.

The team members of the current research used the works mentioned above as discussion and study sources. The group assessed advantages and disadvantages of several themes related to the modern Physics Theories, and these were taken into consideration when making the final decision about which attributes would be taken from the several themes of such theory: difficulties toward concepts; associated mathematical formalism; availability of teaching materials that are adapted to secondary schools; possibilities to make connections with classic topics that can be found in the traditional curriculum; possibilities to make connections with technology; possibilities to produce experimental activities. Within this context, the two courses were chosen and seemed to fit all goals proposed by the research:

The definite sequence was drawn in three years by considering the pilot-course organization and application in previously chosen classes, analyzing the results grasped in classroom work and revising the activities constructed. Below is the sequence of the final topics for both courses.

A) particle-wave duality course:

- **I.** Models in routine life and Physics
- **II.** Waves and particles
- **III.** Introduction to magnetic and electric properties found in matter
- **IV.** Short considerations on electric, magnetic and gravitational fields
- **V.** Electromagnetic field and electrostatic induction
- **VI.** Mechanic waves and light as an electromagnetic wave
- **VII.** Light: color and vision
- **VIII.** Spectroscopy
- **IX.** Bohr´s atomic model
- **X.** Photoelectric effect
- **XI.** Wave-particle duality

B) Particles physics

1. A brief study on radiation and radioactivity: X-rays, a, ß and ? radiation.
2. The atomic model development; the Rutherford experiment.
3. The stability of the nucleus: the discovery of the neutron; the strong force and the a radiation.
4. Cesar Lattes and the mesons: particle physics in Brazil; cosmic rays, accelerators and particle detectors.
5. The quark model: the particle structure; the quarks and the color charge.
6. The neutrino and the ß radiation: energy and momentum conservation; the discovery of the neutrino; the weak force and the ? ß- decay.
7. Conservation laws: strange particles; antiparticles and matter.

[10] Metaphors and analogies are important resources for teaching, although questionable in scientific research, for they allow users to globally appreciate aspects that can be involved in commonly complex situations. By making use of functional and structural comparison, quite often it is possible to communicate ideas that could hardly be communicated with analytical resources.

8. The positron, creation and annihilation of particles.
9. A new conception of the electromagnetic field: the photon as a mediator of the electromagnetic interaction.
10. The Feynman diagrams
11. The particle families: bosons and fermions.

The produced material is available in the site: http://nupic.incubadora.fapesp.br/portal

The list of topics above comprehends a pilot course. Throughout a teaching year, the six Physics teachers were responsible for applying it in 12 secondary-level classes, sixth-semester students (17 or older), between 2004 and 2007.

The analysis was produced by selecting some activities of each course. In this direction, Brockington and Siqueira developed (Brockington, 2005; Siqueira, 2006) the notion of "marker", which proposes contributing to determine the main activities of a specific course. The "marker" idea was designed by Brockington (2005) and modified by Siqueira (2006) to structuralize and analyze a didactic sequence on the dual behavior of light. The "markers" were defined as the main ones in order to know how to establish the pluggings between the constituent concepts of a new bred structure.
From the wave-particle duality course we chose the activities number I, VIII, IX, X and XI as "markers". Form de physics particles course we chose the activities number 1, 2, 5, 7, 9, 11.

Each activity was analyzed using the criteria of knowledge "survival" ("survie des savoirs"), proposed by Chevallard (1991, pag. 54). These criteria are defined in terms of:
i) Consensus, ii) Actuality: Moral and biological ones; iii) Operationalization; iv) Therapeutic; v) Didactical Creativity
These criteria were used as attributes to be verified during the course application in the Secondary-school classrooms. All classes were registered in a video tape and then analyzed.
The results obtained from these analyses have shown us that the most part of the criteria above were with respect to the marker-activities.

Conclusion

The assessment of the strategies to overcome the pedagogical difficulties related to the inclusion of topics from both Contemporary and Modern Physics into the secondary-school level curricula was possible because of the experience gained throughout the project. The results obtained enabled us to state that it is not impossible for such topics to be taught to pre-university students, although epistemological, methodological and educational changes should take place. Our research did not lead to a more conclusive assessment on the level of learning that secondary-school students have, for the primary objective focused on producing a didactic sequence that could be implemented within a real classroom situation. Limits and possibilities to update Physics topics within secondary-level curricula could be defined as collaborative work that was carried out by the team. We believe that the problem of updating and modernizing curricula can be worked on with the involvement of groups composed of researchers in Physics teaching and secondary-level teachers. Classrooms are complex environments under the influence of several factors. Considering such complexity on the whole should be the task of collaborative teams that would be able to bring out teaching proposals based on problem analyses, solution proposals, tests and rebuilding procedures. This task might allow teaching to progress in such a way that it can follow the real background needs of today's individuals.

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