Fantasies, myths and fallacies in Modern Physics teaching: the case of the 3 "R" (radioactivity, relativity, red-shifts

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(*Recebido em 30 de julho de 2000*)

Abstract: *Modern physics practically does not exist in science teaching at Brazilian schools. Science teaching follows the boring linearity of text books with scarce historical information. Otherwise it presents hundreds of standard exercises that corroborate the paradigms of the contemporary science of the 20th century. The present work deals with reflections on an approved project (PROIN/CAPES) to promote the teaching of modern physics as enhanced in the "Special Didactic Laboratory". The project consists of three stages: 1) evaluation of students' scientific knowledge on modern Physics and its history; 2) equipment of the laboratory with classical experiments; 3) reconstruction of the historical contexts of science. The first two stages have already been implemented. The third stage is the most difficult since the promoters are struggling against a scientific education that created myths, fantasies and, therefore, a fallacious teaching of physics. Our approach is one of "deconstruction" of certain facts considered as "truths" in science and in scientific education (the "3 R's" from the title): a) Becquerel never "discovered" radioactivity; b) light deflection from the sun in the 1919 eclipses was never conclusive; c) Hubble never affirmed that the red-shifts were the proof of an inflationary Universe.*

Key words: *physics teaching, paradigms, history of science, sociology of science*

Resumo:. *A Física Moderna praticamente inexiste no ensino de Física nas escolas do país. O ensino de ciência segue sempre sua linearidade cansativa dos livros-textos com* *escassas informações históricas. Por outro lado, esse ensino apresenta um padrão de resolução de centenas de exercícios estilizados que corroboram os paradigmas da ciência contemporânea do século XX. O presente trabalho se propõe a ser uma reflexão baseada no projeto PROIN/CAPES para promover o ensino de Física Moderna na disciplina "Laboratório Especial de Física Moderna". O projeto consiste de três estágios: 1) avaliação do conhecimento científico dos estudantes sobre a Física Moderna e sua História; 2) equipamentos de laboratórios com experimentos clássicos; 3) reconstrução de contextos históricos da Ciência. Os dois primeiros estágios já estão implementados. O terceiro estágio é o mais difícil uma vez que promove uma espécie de saudável "rebelião" contra a educação científica que cria mitos, fantasias e conduz, portanto, a um falacioso ensino de Física. O* modus operandi *é a desconstrução de certos fatos considerados como "verdades" na Ciência e na educação científica (os três "R"s do título): a) Becquerel nunca "descobriu" a radioatividade; b) a deflexão do raio de luz pelo Sol no eclipse de 1919 nunca foi conclusivo; c) Hubble nunca afirmou que o deslocamento para o vermelho (*redshift*) era a prova para um universo inflacionário.*

Palavras-chave: *ensino de Física, paradigmas, história da Ciência, sociologia da Ciência*

1 Introduction

PROIN is a project of the Brazilian Ministry of Education for the integration of graduate and post-graduate courses (Master's and Doctoral degrees). The project proposal approved by the Physics Department of the State University of Maringá, PR, Brazil, aimed at creating a nucleus of a modern physics laboratory. Or rather, to make improvements in the experimental procedures and didactic tools (specific contents and history of science) and to create links with the type of Physics developed at research laboratories (solid state, liquid crystals and photothermic effects).

However, to take this project ahead, two subjects had to be taken into consideration:

1. The knowledge students have concerning phenomena of modern Physics. Or, what are their alternative conceptions?

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2. The role current paradigms have in the choice of themes and standard experiments for the teaching of Physics? What is the dominant orthodoxy today in the teaching of Modern Physics?

The present work will try to show the results of a standard questionnaire on the knowledge of modern physics and the problems related to themes that nowadays are predominant in the teaching of physics of that important period of the science (from the end of the 19th century to the present). The teaching of modern physics takes into account neither the subject of orthodoxy nor the question that paradigms expresses models of explanation and not last realities of an unknown nature.

2 The questionnaire

A questionnaire was submitted to 50 undergraduate students of physics (see table below). The questions were centered on aspects of general culture and on concepts concerning general physics (linked to important concepts of modern physics)

1. What is the principle of the microwave oven?
2. What is the spectrum?
3. Why does the sound of an ambulance at high speed change its frequency?
4. How is the "core" of matter constituted?
5. How was the speed of light determined and what is it value?
6. Define refraction; reflection; diffraction; interference.
7. What is a "black-body"?
8. What is laser and what are its physical principles?
9. In what does the Theory of Relativity consist of?
10. What is photoelectric effect?
11. What is the principle of a simple battery? Draw a battery.
12. What is the basic principle of a photocopying machine?
13. What is the physical principle of a liquid crystal display?
14. Who were Bohr; de Broglie; Schrödinger; Hubble; Gell-Mann?

The results of this questionnaire revealed a teaching based on a poor process of memorization of the phenomena of physics, together with a substandard process of experimentation full of a theory-laden approach. The basic principles of optics, electromagnetism and relativity, found in the answers (of 50 undergraduate students) indicate a certain teaching of physics without any commitment to knowledge and its construction. It is evident that teaching follows a method in which orthodoxy and dogma are present throughout the process of "learning". It is not surprising to verify a very poor scientific culture, as may be measured in the answer to Question 14. The names of the scientists were identified only by an equation or by a model completely dissociated from the context of the particular construction of their theories or experiments.

3 The rise of a new physics and its (hidden) controversies

By the end of the 19th century post-Newtonian scientists affirmed the "end of Physics", similar to the present "end of History", or such other nonsense. The advent of the new century brought to science a necessary change in current direction. The study of the atomic model, electromagnetic phenomena, gravitation and microscopic structures of the matter replaced the Newtonian paradigm, constructing a wonderful new world linking firmly science to technology. The two World Wars and the Cold War were the natural results of the rise of this new science, while the atomic bombs were the "legal sons" of the new physics. With the status of quantum physics and relativity strict orthodoxy reigned in the academy and in research institutes. The paradigms were so strongly established that all contrary models or theories were swept out into a dark corner of the history of science.

In all levels of teaching physics became a mirror for the great centres of the production of knowledge. Every year thousand and thousand of students had to repeat a pasteurized science history and to solve hundred of standard problems to have access to this New Science or "New Deal"!

In the following section we will describe three "classical" cases of standard Physics teaching: radioactivity, relativity and red-shift. Perhaps all of us have received an education in which these three themes were linked to the models that replaced our notions of reality. According to Kuhn (KUHN, 1974), a dogmatic education is necessary to create repeaters and thus maintain the paradigms. Science history is thus reconstructed (or distorted) into a "legal history", eclipsing the possibility of young students and scientists to see the same phenomena from other viewpoints. In this case, science, fantasy and myths become equivalent, even though students, teachers and scientists as a whole are not aware of this condition. This act of unawareness paradoxically maintains and sustains the paradigm, albeit, at the same time, it is the cause of its ruin. Pasteurized science history and pasteurized science conduct us to a fallacious science teaching, de-educating and distorting the process of the construction of knowledge.

3.1 The case of radioactivity and the strange Becquerel's "discovery"

One of most known episodes in the history of physics is the discovery of radioactivity by Nobel laureate Henri Becquerel. History describes the discovery as a mere accident: an uranium compound and a photographic plate kept together in a drawer, while the revelation on the plate showed signs of radiation.

Despite this "legal version", the history is very different and complex. First of all, the discovery of X-rays by Roentgen on November 8, 1895, must be revisited (for references of this section see (MARTINS, 1990). He perceived that a plate covered with a fluorescent material became luminescent when a cathode rays tube was turn on. He analyzed the properties of this new kind of "ray": no deviation in prisms and lenses or magnetic fields; no polarization, regular reflection or interference (all these properties had been described by Roentgen in an article published in December 28, 1895).

Roentgen article immediately provoked the rise of an enormous quantity of research work: Poincaré, Perrin, Oudin, Barthélemy, le Bon, Charles Henry, Becquerel, Niewenglowski, and others.

To make a long story short, it is important to say that Becquerel followed a relationship between fluorescence and X-rays: a false track that conducted to several future discoveries (according to present knowledge, there is no direct relation between luminescence and the emission of X-rays).

In his experiments with uranium compounds (luminescent or not) Becquerel verified that invisible radiation is emitted (with optical properties different from X-rays). He also tested metallic uranium and verified again the emission of radiation. Becquerel linked these observations to the phenomenon of an invisible phosphorescence and not to a new kind of phenomenon. Repeating some of Becquerel's works, Stewart arrived at the conclusion that Becquerel's rays are transversal electromagnetic waves. Le Bon, however, failed to verify the effects of reflection, refraction and polarization.

In 1898, Mme. Curie found that another element, thorium, emitted radiation like uranium. She wrote: *Uranic rays are frequently called Becquerel's rays. It is possible to generalize this name, applying it to thoric rays and to all similar radiation. I will denominate "radioactive" the substances that emit Becquerel's rays. The proposed denomination of "hyperphosphorescence" for this phenomenon gives me a false idea of its nature.*

Therefore, it is necessary to credit Mme. Curie with the discovery of radioactivity. Becquerel was one more "victim" of the theoretical expectations responsible for the creation of observations, or unknown epi-phenomena and fallacies.

3.2 The case of relativity and the solar eclipse of 1919 in Brazil

In May 29, 1919, Arthur Eddington sent two expeditions (Sobral, in Brazil, and Porto Principe, in the African west coast or Gulf of Guinea) to register the deflection of star lights (by the sun's gravitational field). Results from the theory of relativity predicted double the value given by Newton's gravitational law. This test was considered crucial for the general theory of relativity (for references on this section see (MAMONE CAPRIA, 1999; ZYLVERSZTAJN, 1989).

This kind of observation is very difficult because there are many parameters towards reliable results: atmospheric turbulence derived from hot air, aberrations (sphericity and chromaticity) of the optical components and the technical problems related to the focus of telescopes.

The "legal history" of physics registers that the results were: in Sobral: 1.98" $\pm$ 0.12"; in Principe: 1.61" $\pm$ 0.30". The theoretical value predicted by Einstein in 1911 was 1.74" (by Newton's theory this value was 0.87"). Consequently, results obtained by the two expeditions were declared the "crucial observation" to prove the Einstein's theory of gravitation. Eddington worked hard to declare this "victory". However, parts of the results were neglected by the Eddington's teams. For example: Einstein's theory predicts that k2 Tauri should have the greatest displacement with 0.88". In Sobral, the displacement registered was 1.00" for that star.

In Sobral, 26 photographic plates were obtained, but only seven were in good conditions (from the 4-inch telescope, and other 19 from the astrographic). With regard to the seven good plates the mean deflection value was significantly greater than the value predicted by Einstein's theory. The 19 plates from the astrographic telescope produced the incredibly mean value of 0.86", e.g., very close to the Newtonian prevision (0.87")!

In Dyson, Eddington and Davidson's report the difficulties with equipment were implicitly registered too: *When the [astrographic] object glass is mounted on a steel tube, the change of scale over a range of temperature of 10° F should be insignificant, and the definition should be very good.*

In Sobral temperatures ranged from 75°F (at night) to 97°F (in the afternoon)! Despite many technical problems and atmospheric conditions Eddington declared the veracity and reality of Einstein's relativity theory.

Taking into consideration the effects of atmospheric diffraction and optical aberration of the telescopes, posterior analysis of the results registered at Sobral by other researchers showed a final result ranging from 1.95" $\pm$0.09" to 2.16" $\pm$0.14". Other eclipses at different places of the planet, especially those of 1922 and 1952, showed a great disparity of results. It indicated the difficulties to obtain such measurements. In spite of this, Eddington played a great influential role in the acceptability of the general theory of relativity. The heritage of this "scientific enterprise" is deep in our culture and it has been directly responsible for the ranking of Einstein's theory in the category of cult or dogma.

3.3 The case of red-shift and cosmic background radiation (CBR)

In their article "Early Cosmic Background" (for all references of this section, see ASSIS and NEVES, 1995, 2000), Le Floch and Bretenaker discussed who were the first to measure the cosmic background radiation characterized by a black-body temperature of ~3 K. It is a well known fact that the first prediction of this temperature based on the big bang hails from Gamow's collaborators Alpher and Hermann and their 1948 publications. Le Floch and Bretenaker called attention to a 1956 Ph. D. dissertation by Le Roux in which the author reported measurements of the sky temperature as 3 $\pm$ 2 K. The measurement and presentation of the thesis was thus earlier than Penzias and Wilson's famous paper of 1965 which is usually considered to report the temperature's first measurement. Below we will give other even less well known results.

The earliest "temperature of space" known to us is due to Guillaume. It was published in 1896 in a paper with the same title. He estimated the flux of energy due to star light and employed Stefan-Boltzmann's law related to the bolometric flux of radiation emitted by a black body (obtained in 1879 and 1884) to arrive at a temperature of 5 to 6 K. In his book The Internal Constitution of Stars, Eddington utilized the same procedure to arrive at a temperature of space as 3 K. Although he did not quote Guillaume's paper, his words ("The total light received by us from the stars is estimated to be..." and "This is sometimes called the 'temperature of interstellar space'") seem to demonstrate that the value of this temperature was of common knowledge at the time of the publication of the book in 1926.

Guillaume and Eddington were discussing the temperature of space due to the radiation emitted by the stars. The definitive establishment of the existence of other galaxies not belonging to the Milky Way occurred only in 1924 with Hubble's discovery of Cefeid variables in some nebulae. In 1929 he obtained the famous law relating the red-shift of distant galaxies with their distance to us.

Concerning Hubble and the red-shifts law, it is important to quote a comment of "The Realm of the Nebulae", pp. 122-123 (when Hubble started to find red-shifts of very high values): *This explanation interprets red-shifts as Doppler effects, that is to say, as velocity-shifts, indicating actual motion of recession. It may be stated with some confidence that red-shifts are velocity-shifts or else they represent some hitherto unrecognized principle in physics. ... Meanwhile, red-shifts may be expressed on a scale of velocities as a matter of convenience. They behave as velocity-shifts behave and they are very simply represented on the same familiar scale regardless of the ultimate interpretation. The term "apparent velocity" may be used in carefully considered statements, and the adjective always implied where it is omitted in general usage.*

Cosmic rays had been discovered by Hess in 1912. Regener measured the flux of energy due to cosmic rays and concluded in 1933 that it had the same order of magnitude as the flux due to star light belonging to our galaxy. Since it had been known since 1928 that the greater part of cosmic rays originated outside our galaxy, Regener could estimate the temperature of intergalactic space utilizing once more Stefan-Boltzmann's law. By his measurements he arrived at a temperature of 2.8K. Walther Nernst utilized Regener's measurements and published a paper in 1938 called "The radiation temperature of the universe".

We should mention briefly the work of Herzberg in 1941 (based on observations made by A. McKellar) in his discussion on cyanogen measurements in interstellar space. Although Herzberg found a temperature of 2.3 K characterizing the observed degree of excitation of the CN molecules in equilibrium in a heat bath, he concluded that this temperature "had only a very restricted meaning."

In 1953-54 Finlay-Freundlich proposed a red-shift mechanism proportional to the fourth power of temperature in order to explain some measurements of several stars. Applying his formula to the cosmological red-shift (Hubble's law) he estimated the mean temperature of intergalactic space between 1.9 K and 6.0 K. When discussing Finlay-Freundlich's work Max Born proposed that it might be due to a photon-photon interaction. Following this approach he concluded that "the red-shift is linked to radio-astronomy." This prediction anticipated by 11 years the work of Penzias and Wilson with a horn antenna built to study radio waves.

4 Conclusion

Unfortunately, the subjects discussed above are so vast to discuss briefly in this paper the effects of "theory-laden" or theoretical expectations in the work of science and in the educational teaching-learning process. It is sufficient to say that it is possible to construct a didactical practice (theoretical or experimental classes) keeping in mind the contingencies of the nature of science and the role of the paradigms to maintain the status quo and to promote social communication, thought schools, but, also, myths, fallacies and scientific idols.

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