Teaching Concepts of Physics and appointing the Nature of Science through Historic Scientific Experiments

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ABSTRACT

Traditionally, the teaching of science in schools is focused mainly in providing the knowledge of theories and facts or the obtainment of technical skills. A further step towards a science-literate strategy would be to focus more in the understanding of the physics' laws through the exemplary line of reasoning followed by the scientists who introduced them, as well as the repetition of the conducted experiments. Some of those experiments contributed to the establishment of revolutionary theories; in this way they have influenced the evolution of the ideas in science and the society.

In this paper, we propose the presentation of the experiments of Galileo concerning the falling objects; they are related to the concepts of inertia and gravitational force, thus helpful in understanding the Newton's laws of Kinetics and Gravity.

Simulations of the historic experiments must be used as well as simple repetition of the experiments in class. The educational material must be given in a multimedia form, must be accessible by any school and should be accompanied with work sheets; thus it can be used in different ways. It should serve the aim of engaging the student in the scientific process that was followed by Galileo.

INTRODUCTION

The aim of a modern educational process is to prepare and enable citizens (European Commission, 1995; AAAS:1989; AAAS:1993; Millar, 1997: 101):

a) to understand basic principles and concepts of science;
b) to follow the scientific methodology in dealing with their daily life problems and to apply scientific knowledge for taking personal and social decisions;
c) to perceive science as a human achievement;
d) to conceive the value of scientific knowledge as well as the limits of its power.

After many years of interest in the scientific literacy of citizens, researchers in the field of natural sciences education keep on seeking an effective way of approach by the trainees not only of the acceptable scientific knowledge (i.e. the final results of the scientific exercise) but also of the methodology of science, that is the way of scientific work (De Boer, 2000; Hurd,1988; Laugksch, 2000; Lederman & O' Mailey, 1990; Akerson, Abd-El-Khalick & Lederman, 2000; Lederman, 1999). Scientific theories should be presented in such a way that would place emphasis on the fact that these theories constitute sets of inter-related concepts and that every theory offers a framework to understand and comprehend an empirical field (Millar, 1998).

OBJECTIVES

One of the most important questions concerns the extent to which an indirect teaching approach on the nature of science (NoS), including lectures, discussions and incorporating scientific activities like experiments, projects, research etc., should be used. Answers to the aforementioned question differentiate to a great extent (Palmquist & Finley, 1997; Lederman & O'Malley, 1990; Moss, 2001; Rydder et al., 1999), (Bell, Lederman & Abd-El-Khalick, 1998; Bell, Lederman & Abd-El-Khalick, 2000; Akerson et al., 2000; Bianchini & Cobern, 2000). The proposal presented in this paper is based on the framework that connects the experience of 'doing science' to the direct and explicit teaching of the NoS features through the use of elements from the history of science (Akerson et al., 2000, p.297).

The history of science should be incorporated in a way that allows the presentation of the historical evolution of scientific standards and physics' concepts, which led to the formulation of the theories that constitute, at present, the foundations of scientific knowledge. Elements from this historical evolution should be included both in the curricula of the various educational grades (AAAS:1993) and in the teachers' training programs (Dimitriadis, P. et al., 2001). In addition, the historical, geographic and social context within which these theories were developed should be made known to the students. By presenting the biography of the scientists who participated in the development of the scientific theories, the social character of science is better perceived and its nature as a human achievement is properly highlighted.

It is evident that out of the total of the scientific ideas one should select and present the more useful and significant parts of achieved scientific knowledge, like particle structure of the matter, the fundamental interactions, etc. Moreover, each thematic unit chosen to be taught should give answers to fundamental questions that concerned the scientists who participated in the formulation of the respective theories. More importantly, however, these questions should generate the interest of students and drive them to further study the specific topic. Thus, for example, the following questions could be asked:

a) How do matter composing particles interact with each other?
b) Could the particles forming the matter be created or disappear?
c) Where does the stellar energy to which we owe our existence come from?
d) What makes the stellar bodies move and how is their movement determined?

e) Can we predict whether a stellar body approaching the earth is going to collide with it?
f) Which is the cause of the movement of terrestrial and celestial bodies?

In this particular case, we choose to present certain basic experiments that are considered as milestones in the development of the concepts of physics, since the methodology followed and the way in which these experiments have been performed have contributed to the establishment of scientific methodology. These experiments should be presented in such a way that the steps of the scientific method are explicitly demonstrated. Experiments like these, could constitute the basis for teaching in class the key concepts of physics, like those of inertia and gravity, the laws of Newton, etc. The teaching approach is addressed to middle school students and students of the first grades of the high school.

The basic thematic units we choose are the following:

a) The Newtonian mechanics;
b) The theory of electromagnetism, and
c) The structure of the matter.

We present these topics in close relation to the historical experiments performed, respectively, by Galileo, Faraday and Rutherford.

Educational Software

Our purpose is to build up a collection of web pages within the European School's of Brussels III site. The didactic material included is addressed to both teachers and students and will have the form of hypertexts, visualizations of the simulation models and static pictures related to the theories. Work sheets will be available in a later stage.

Information and communication technologies are essential in meeting the objectives of the network. Since we strive to encourage students to become familiar with some historic experiments, an ICT platform is needed to facilitate this. The development of this software has the following general objectives:

a) To assist in creating proper solutions for problems arising during the teaching of the respective concepts, like facing the students' misconceptions
b) To be used by students in order to absorb and comprehend the respective concepts.

Such software packages contain:

a) The presentation of experiments as performed by the scientists who conducted them or their inspirers, along with the questions for which answers were sought when performing these experiments;
b) The technical problems that had to be faced by those who designed these experiments;
c) The established perceptions that were overturned by carefully analysing and interpreting the experiments' results;
d) The presentation of the geopolitical context in which the aforementioned ideas had been developed;
e) Simulations / visual representations of the experiments, highlighting the basic parameters of the phenomenon and their inter-relationships;
f) Study / teaching plans and worksheets.

An important feature of this software is the multimedia worksheets, which have the following characteristics:

a) Multiple representation of instructions in picture, video and/or text format;
b) The possibility to highlight the information acquired at the empirical field. For example, there is a possibility to observe a fast developing phenomenon in slow motion, so that the student can watch each different picture thus becoming able to describe in detail each different step of the experiment
c) Model creating capabilities for the natural phenomena the students are studying in the course of the empirical activities;
d) Presentation of the scientific model for the particular natural phenomenon properly adapted to the students' cognitive level.

In this way, students analyse in detail their empirical data and identify the basic characteristics of the phenomenon, resulting into the scientific model that describes this phenomenon. Thus, the student realises that making models of the natural systems is a basic element of scientific methodology (Arbanitakis D., Dimitriadis P., Papatsimpa L.; 2001).

Computer based techniques like hypertext and visualization of simulation models serve as a means to overcome basic obstacles in learning processes.

The first drafts of the didactic material are created using the authoring environment of Macromedia's Flash MX which can provide Web pages of sufficient quality. The Action Script included, is quite powerful in supporting the simulation models presented (and at the same time quite easy to understand). We investigate the possibility of using other products, if necessary, in a later stage.

Some of the animated pictures are built by using Animation Shop by combining static pictures – frames, created under the Paint Shop Pro. It is an environment providing tools for image manipulation.

The outcomes will be available to schools worldwide. Initially only the partner schools will actively participate in providing and testing the educational material.

Once the final version of the web-site is fully operational, all schools that have access to the WWW will be able to view and study the information presented, and will be enabled to actively participate in the process of exchanging ideas and providing additional information.

Teaching methodology

Students were working in groups of two persons on the basis of the worksheets under the guidance of the teacher. The worksheets were developed on the basis of guided research. By using electronic worksheets, the teacher was able to easily enter into a Socratic dialogue with the students who were, thus, assisted in dealing with their preconceptions on the specific phenomenon. The teacher is supported in introducing the scientific model through the use of simulations or visual representations of the natural process, simple modeling of real objects (e.g. the material point) or forces, shown by the video projector. The teacher, using suitable slides, guides the students to identify the common characteristics of activities conducted in the classroom or of the phenomena they watched on the video screen, so that they can draw conclusions and use the scientific terminology.

Thematic Unit 1-Unifying Earth with Heaven, the Newtonian synthesis

This thematic unit refers to the laws that were formulated by Newton. These laws govern the movement of both celestial and terrestrial bodies, the law of the universal gravity, as well as to the great influence of the aforementioned views on shaping the socio- philosophical ideas of the 17th and 18th centuries.

The Newtonian perception of the world created such a great response that it also influenced fields beyond Physics and Astronomy. Physics' principles and the mathematical way for calculating their impact provided the model for all subsequent scientific development. It consolidated the perception that natural phenomena can be explained in terms of mathematics and physics, and that nature can evolve without the intervention of external actions, like God, although Newton himself considered that the verification of his theory certified God's existence. It also influenced significantly the social beliefs of that time and signaled the beginning of formulating various social systems theories. A lot of people considered that it is possible to design and operate a system of government in a way similar to the Newtonian solar system, which under the influence of different forces/factors would soon reach a stable state of equilibrium.

Moreover, the development of Newtonian mechanics is a characteristic example of a scientific theory that was progressively built by following the distinctive steps of scientific methodology, that is:

A. The validation of different scientific statements through a multiple process of experimental confirmation, the use of parameters to describe natural phenomena and the identification of quantitative relations among these parameters.
   - ✓ **Galileo** designed and conducted experiments with admirable for his time accuracy, in order to confirm Aristotle's postulations (which were the prevailing ideas of his era) on the bodies' movement and fall. He was, thus, lead to defining the law of inertia, as well as the laws of movement under constant acceleration and of movements influenced by the resistance of the air (projectile motion).
   - ✓ **Huygens** studied collisions and, taking into account the notion of relative movement, concluded to the principle of maintained thrust.
   - ✓ **Keppler**, elaborating further the very accurate astronomical observations of T. Brache, concluded to the empirical laws governing the movement of the planets.

B. The synthesis of individual scientific true statements – Identification of a small number of principles ~~/ laws~~ explaining the experimental results.
   - ✓ **Newton introduced**:
     The notion of mass as a measure of inertia,

The notion of force and its qualities (the action-reaction axiom),
The three laws governing movements,
The law of universal gravitation, and
explained the empirical laws on the movement of planets, based on the 2^{nd} of his laws and the law of universal gravitation.

By selecting the above topic we can:

- highlight the role of observation and experimentation in the scientific methodology, the clash of scientific ideas that lead to the Newtonian perception of the natural world, as well as the influence of Galileo's and Newton's theories in shaping the modern concepts on the movement of terrestrial and celestial bodies;
- present the whole of Newton's synthetic theory integrating the applicability of the same laws on the movement of terrestrial and celestial bodies, a set of ideas that is one of the most important ones in mankind's cultural heritage;
- familiarise the students with the above set of concepts, a fact that will help them in seeking for answers on the fundamental questions of mankind concerning the universe, its creation, its size, its evolution, etc. Almost all human civilizations, from antiquity to today, have been concerned with similar questions, which stimulate the strong interest of present students.

Educational objectives

We distinguish two types of educational objectives: Those concerning the comprehension of concepts and those referring to obtain skills in relation to:

Physics

The student should:

- Be familiar with the basic concepts of Mechanics: mass, momentum, acceleration, force;
- Recognize them through specific activities (like the use of air-table fabricated by simple materials and a simple tribometer, as well as that the force of friction makes bodies decelerate and finally stop);
- Qualitatively associate the concept of inertia to perpetual movement (Galileo's experiments);
- Qualitatively associate the concept of acceleration (how fast or slow a body starts or stops) with the body's mass and the force exerted upon it;
- Describe the qualitative characteristics of his every day experiences using Newton's 2^{nd} law;
- Identify in simple activities conducted both in the classroom as well as in his daily life the bodies upon which a force - and the reaction - is applied by relating the application of these forces to the change in the bodies' movement;
- Use the terms action/reaction to explain phenomena he / she observes in his / her daily life;
- Know that gravitational interaction is exerted from a distance between all bodies with a mass, thus being of a universal character;
- Know the law of universal gravitation and qualitatively explain on the basis

of this law the movements of planets, stars, comets, tides, etc.

- Be acquainted with the three laws of Newtonian Mechanics concerning the movement of bodies and comprehend that they are universally applicable.

History

The student should:

- Know the scientific achievements of Europe during the Middle Ages and the Renaissance;
- Appreciate the role of the church in shaping the society and the ideas during the Middle Ages;
- Comprehend the importance of Renaissance for the European development in the modern times.

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