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Learning Optics from the History

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Learning Optics from the History

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Abstract. A number of studies have described the benefits of the incorporation of History and Philosophy of Science (HPS) for learning, and teaching science as a process, for promoting conceptual changes, and a deeper understanding of scientific ideas.
Physical Optics is a topic of difficult comprehension, and this fact was also observed at thePontificia Universidad Católica Argentina when students received traditional instruction. This article describes a project to improve the teaching of interference, and diffraction of light within a historical context. Care was taken in developing the line of historical thought, and the study of the hypotheses of the nature of light in proper chronological order.
In order to assess the outcome of this methodology, surveys on the subjects of interference, and diffraction of light were conductedduring three consecutive years. During the first year a textbooks based teaching without historical insight was imparted; later HPS based methods were introduced. The results show that students show more enthusiasm in lectures where the didactics uses HPS materials, and this methodology contributed to improve the students´ performance, increasing the percentage of correct answers in the exams.

1. Introduction

Studies reported in bibliography have shown that teaching physics with lectures based on the structure proposed in books, may led to make Optical physics a topic of difficult comprehension ([1],[2]).This issue was observed in a group of students of Food Engineering from Pontificia Universidad Católica Argentina (UCA) during the dictation of Physics 3 (subject that comprises electricity, magnetism and optics) when a routine teaching, as reflected in textbooks without historical insight was imparted. With these students it was also observed that even though they had acquired expertise in handling equations and formulae, they didn't understand the real meaning o had a distorted vision of the described physical phenomena.
Given this fact, and knowing that physics teaching represents an interdisciplinary and complex activity, the need to find new strategies to improve the teaching-learning process was raised.
Physics, and History and Philosophy of Science (HPS) are some of the areas of knowledge that make essential contribution to the physics teaching. Many studies have reported the benefits of this approach for learning, and teaching science, as a process, for promoting conceptual changes, and a deeper understanding of scientific ideas ([3]-[6]).

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2. Method

This study was carried out with students that took a basic optics course (Physics 3) at an Argentinean University (UCA). This course was taken by students of Food Engineer of the Agrarian Sciences Faculty. The number of students that take de course is about 20 and all of them received the same instruction. In order to assess the outcome of this methodology, surveys on the subjects of interference, and diffraction of light were conducted, before and after classes, during three consecutive years. During the first year a routine teaching, as reflected in textbooks without historical insight, was imparted; later HPS based methods were introduced.

The active methodology applied, works with problems and questions. Classes based on selected observations of optical phenomena by scientist since the XVII century were presented as triggers of ideas on the wave nature of light. Care was taken in developing the line of historical thought, and the study of the hypothesis of the nature of light in proper chronological order.

2.1 Historical line

The historical line begins with Rene Descartes (1596-1650), who was the first to publish the law of refraction in a correct way, and without which no substantial progress in optics would have emerged. He incorporated this law in a physic-mathematical theory which constituted the starting point for the investigations of Hooke, Huygens and Newton giving a renewed impetus to optical research and a new direction [7]. Descartes´s contributions to optics are contained in two treatises appended to the "*Discourse de la method*" (1637): "*The Dioptrique*", and "*Meteores*". He employed three mechanical analogies in his treatment of light. In the first place, the light is considered as a pressure transmitted instantaneously through matter; second, the impulse we call light is "like tendency of the juice in a barrel of grapes to flow out of a hole in the bottom while grapes remain stationary". Finally, the light is compared to a moving ball [8].

Descartes´ work in optic exercised a peculiar dominion over the minds of investigators in the following generation. Those who questioned the Cartesian model proceeded to the construction of their own [8].

Pierre Gassendi (1592-1655), antagonist of Descartes, was the first influential philosopher of atomism in the modern world. He conceived light as a stream of tiny spheres transmitted to us at high speed.

Francesco Maria Grimaldi (1618-1663) was a Jesuit who worked in Bologna. Grimaldi's more famous discovery was the diffraction of light. He created a pinhole through which he allowed light from the sun to enter a darkened room and fall on a screen. He discovered that the shadow was larger than it should have been given the conical nature of the beam. Grimaldi argued that light must be a fluid. The name diffraction was chosen by Grimaldi because the effect reminded him of how a flowing fluid splits apart when a thin stick is placed in its path. The latin "difractio" means "break apart". Through various experiments, including prismatic experiments, he sought to demonstrate how reflection, refraction and diffraction can modify light so as to produce sensations of colors [8].

Walter Charleton (1619-1707), an English physician, was attracted to the rival exponents of a New Philosophy: Descartes and Gassendi. In 1654 appeared Charleton´ s mayor work entitled "*PhysiologiaEpicuro-Gassendo-Charletoniana*", with the subtitle: "*A fabric of Science Natural, upon the hypothesis of atoms*" [9]. Charleton stated that atoms are without color and bodies differ in color owing to their surface textures, and their influence upon, or modification

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of rays of light. Those rays are streams of minute particles either emitted directly from their source or reflected from the surfaces of the bodies where they are influenced by the excrescences and cavities found there [9].

Robert Boyle (1627-1691), brought out a book in 1664 that radiated Cartesian influence, and exerted influence upon Newton: “Experiments and Consideration Touching colors”. Boyle drew for the corpuscular theory of light and performed experiments with prisms to demonstrate that colors are not to be thought of as inherent in the objects, although light can be influenced by the surface texture of objects and so appear colored when reflected to our eyes [9].

In the same period of a few years during which Boyle was completing his “Experiments touching colors” and Newton initiating his career in experimental optics, Robert Hooke was also investigating colors.

Robert Hooke (1635-1702) was Robert Boyle´s assistant. Boyle perceived Hooke genius for devising simple yet conclusive experiments, and in 1662 The Royal Society appointed Hooke curator for experiments. From drawings for the Royal Society of microscopical observations come his mayor work “*Micrografia*” in 1665, which included speculations on light. For Hooke, white light was a simple kind of vibration and colored light was a modification of white light. He supposed that light was some kind of non-periodical wave that would acquire different properties near the edge of the light beam ([10]). Hooke discovered and explained the interference phenomena occurring between two lenses, later known as “Newton rings”, introduced the idea of wave front, and explained its deflection at boundary between media and described diffraction [11].

When Newton started his studies about light, light is thought to be material or activity of a material substrate. The colors appear because of modifications of the light. ([12])

Newton´s early considerations of light and color are recorded in his notebooks. One of the sources first drawn upon by Newton, from which he took notes, was Walter Charleton’s “*PhysiologiaEpicuro-Gassendo-Charletoniana*” ([13]). At the time, Newton made notes from his readings of Descartes’s “Dioptrique” and “Meteores”. He had also read Boyle’s “*Experimental History of Colors*”. The notes reflect the state of opinion on colors.

Newton sent to the Royal Society in 1672 a letter setting out his experiments and ideas on light and color. Newton’s key suggestion was that white light is a mixture of all the colors of the rainbow which are separated by being bent by different amounts as they pass through the prism. He also suggested that light was made up of a stream of tiny particles. The statement that white light is a “heterogeneous mixture of differently refrangible rays” led to a strong controversy between Newton and Hooke, Huygens and Pardies[14].

Ignace Gaston Pardies (1636-1673), a french Jesuit, left unpublished a work on Optics “*Traité complete d’optique*”. Pardies considered light as a wave, and challenged Newton´s explanation of his experiment thereby forcing Newton to clarify his ideas. Pardie´s letters and Newton´s replies are found in the Philosophical Transactions of the Royal Society for 1672 and 1673 [15].

Christiaan Huygens (1629-1695) was a prominent Dutch mathematician and scientist. Huyguens was influenced by Descartes, his father´s friend, and he was by Hooke´s Micrografia. Huygens attributed to the father Pardies his first convictions in the wave concept. In 1678, Huygens published his “*Traité de la Lumiere*”, where he enunciated the principle according to which every point the “aether” upon which the luminous disturbance falls may be regarded as the center of a new disturbance propagated in form of spherical waves. These waves combine in such a manner that their envelope determines the wave front at any later

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time. In his proposal, the waves were longitudinal. Huygens discovered polarization: each of the two rays arising from refraction by cal-spar may be extinguished by passing it through a second crystal of the same material, rotated about the direction of the ray. Newton interpreted this phenomenon assuming that the rays have sides [16].
From his extensive experimentation, Newton concluded that certain of the implications of both theories (light as a particle, and light as a wave) were inescapable and tried to combine them. In the second edition of *Opticks* (1704), Newton included "Queries" that contained speculations on matters about which he was in doubt. Newton´s successors attributed to him an espousal of the corpuscular theory [17]. The rejection of the wave theory on the authority of Newton led to its abeyance for nearly a century, with exceptions such as Leonhard Euler (1707-1783) [16].
Tomas Young (1773-1829) in the early 19th century, put forth a number of theoretical reasons supporting the wave theory of light, and he developed two enduring demonstrations to support this viewpoint. With the ripple tank he demonstrated the idea of interference in the context of water waves. With the Young's interference experiment, or double-slit experiment, he demonstrated interference in the context of light as a wave [17].

2.2 Activities
The reading materials that are delivered to the students consist of extracts from books, reproductions of letters and papers, and assays performed by members of the physics' department. They contain information about the socio-cultural environment and personal life of the scientist considered, and the influence of these facts in their work. The personal background information about scientists' experiences, efforts and struggles to make important discoveries are included because students often do not fully recognize that scientific knowledge was created by people who have limitations, need to work hard and must go through struggles in order to discover new phenomena or invent new theories.
The material also includes detailed description of the experimental work and conclusions of the scientist in order to recreate them in the laboratory. The students are stimulated to do a search in order to get more information about the topic.
At the beginning of each class, a debate based in the students' readings is performed. They are motivated to look for connections and relations between the data obtained. Then selected experiences are realized, and the results are analyzed following the line of thought of the authors.

2.2.1. Class 1
The students recreate the prismatic experience described by Descartes. His conclusions and historic context are analyzed.

2.2.2. Class 2
A discussion of the readings about Gassendi, Grimaldi, Charletonand Boyle is performed. The students recreate Grimaldi's experiment about refraction, and Boyle's prismatic experiment. The results are analyzed following their line of thought.
An introduction about Hooke and Newton is realized, and reading material including Hooke's and Newton's life and work is delivered. This material contains extractions of Newton's notebooks, translations of his letters presented to the Royal Society, and translations of the letters exchanged with Hooke and other philosophers.

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2.2.3. Class 3
The relationship and work of Newton and Hooke is analyzed. The “Experimentum Crucis” is performed, and it is compared with the prismatic experiences previously realized by other scientist. The conclusions proposed by Newton are analyzed.
A debate about the evolution of the theories, based in letters exchanged between the scientists of the XVII century is performed. Particular emphasis is made in the influence of the exchanges between Newton, Hooke, and Pardies in the evolution of Newton’s Optick.

2.2.4. Class 4
Huygens’s theory is analyzed, and Young’s Interference experiment is performed. Emphasis is made in the analysis of the results and the reaction of the colleagues.

3. Results
The implementation of history of science as a conductor was proved to be a useful tool in several aspects.The students showed more interest in the subject, and the question " Why that hypothesis didarise?" became something natural. The laboratory practices also have shown to be more productive for the 90% of the students (in average).
They showed a deep understanding of the concept that physics describes the nature by means of models that allow to describe and represent a number of phenomena. Based in the information obtained, the students realized the way in which some of these models grow up. Emphasis was made in the fact that the theories described in books don’t appear obviously directly from observation, because from the same starting fact (as prismatic experiments) different conclusions can be obtained.
The proposal had a good acceptation, and it had slight modifications in the successive years, such as the increase of material available, some of them were results of the students’ bibliographic search.
It was possible to follow the planned classes's cronogram, without alteration of the planification for the hall subject
Even though this method requires a bigger dedication and effort by the students for the extra activities like reading the text previously to the class, they prefer it over the book based method. The percentage of preference is over the 85%.
The debates showed that it is possible to get the humanization of this physics’ area, and see the scientist as common persons with particular interests.
In addition, the results of the exams show an incrementof the percentage of correct answers in the exams, which reveal a higher degree of understanding of the students.

Final comments and conclusions
The object of this proposal is that the students achieve a deep comprehension about optical physics. This project is based in the concept that model evolution must be considered in physics teaching, with emphasis in the fact that theories are representations of the nature, but not the nature itself.
The study encompasses the evolution of the theories about the nature of light. Experiences that were the basement of the theories proposed by the different scientist are reproduced. Emphasis is made in prismatic experiences because each one of the natural philosophers did them with different objectives, and the experiments are alike but not equals. Particular emphasis is made in Newton´ notebooks for several reasons. To begin, it allows the students

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to see the way in which the knowledge of a scientist evolves: first, read and analyze all the information he can get; then, based in logical thoughts and experiments, adopt the theories that consider appropriated and dismiss the others. Besides, it also allows to see how new ideas can emerge based on them. The analysis of the arguments between Newton and Hooke and Pardies among others clearly shows that the dispute can be useful for the construction and justification of theories. It also shows how the math based theories are a possible way to describe the nature, but only that.

The results show that the students reveal a bigger interest in the subject and a higher degree of understanding of the subject.

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