"A LITTLE LEARNING IS A DANGEROUS THING": THE NATURE OF SCIENCE AND SHORT HISTORICAL ACCOUNTS

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Abstract:

History of science may help to transmit relevant messages about the nature of science. There are, however, many difficulties concerning an efficient educational use of historical episodes. This paper addresses this educational problem, using a case study: a description of Thomas Young's contribution to the wave theory of light that was used in a short high-school level course on the history of optics. In this particular case, the omission of several features of Young's contributions has led many students to a misunderstanding of his role in the establishment of the wave theory of light and also has conveyed inadequate messages concerning epistemological issues. Starting from the case study, this paper discusses how the absence of historical information or its excessive simplification may promote a naive or faulty view concerning the scientific endeavor. Of course, in educational settings it is impossible to present a detailed historical account of scientific episodes. It is necessary to choose which historical details will be introduced, and which scientific, metascientific and sociocultural features of each episode must be included or can be omitted. This paper suggests some criteria that can help this choice, taking into account the educational aims in view.

Keywords: *epistemological mistakes, historical simplification, history of science, nature of science, Thomas Young.*

Introduction

It is currently accepted that the introduction of history of science may help to transmit relevant messages about the nature of science (Matthews, 1989, 1992; Abd El-Khalick & Lederman, 2000; Gil Pérez *et al.*, 2001; Lederman, 2007). There are, however, many difficulties concerning an efficient educational use of historical episodes (Martins, 2006; Höttecke & Silva, 2010). What types of historical accounts should be used for teaching about the nature of science? How detailed should be the history of science introduced in science teaching? A few guidelines have already became clear, such as the need to avoid pseudohistory (Allchin, 2004; Whitaker, 1979), but there are other difficulties in choosing an adequate approach to history of science in teaching about the nature of science.

This paper addresses this educational problem, using a case study: a description of Thomas Young's contribution to the wave theory of light that was used in a short high-school level course on the history of optics intended to communicate some relevant messages about the nature of science (Forato, Martins & Pietrocola, 2010). In this particular case, the omission of several features of Young's contributions has led many students to a misunderstanding of his role in the establishment of the wave theory of light and also has conveyed inadequate messages concerning epistemological issues.

This paper presents a short account of the aforementioned course on the history of optics and its analysis, giving special emphasis to the specific treatment of the contributions of Thomas Young and Augustin Fresnel to the establishment of the wave theory of light and the mistaken interpretation of the episode by the students. Starting from the case study, this paper discusses how the absence of historical information or its excessive simplification may promote a naive or faulty view concerning the scientific endeavor.

Of course, in educational settings it is impossible to present a detailed historical account of scientific episodes. It is necessary to choose which historical details will be introduced, and which scientific, metascientific and sociocultural features of each episode must be included or can be omitted (Forato, Martins & Pietrocola, 2012a). This paper suggests some criteria that can help this choice, taking into account the educational aims in view.

Methodological approach

The nature of light gave rise to debates and controversies all over the history of science. During the 18th century most authors accepted the corpuscular theory of light; it was replaced by the wave theory of light in the first decades of the 19th century. This historical change has been treated as a nice example of scientific revolution that can be applied in educational settings (Kuhn 1977; Levitt, 2000). In dealing with this conceptual transformation, the experimental contribution of Thomas Young (1778-1829) and the mathematical handling of wave interference and diffraction by Augustin Fresnel (1788-1827) are usually emphasized (Pietrocola, 1992). There are other facets of this episode, such as metaphysical presuppositions concerning the ether (Martins, 2012; Nercessian, 1984) and controversies about concepts, ideas and methodological prescriptions (Cantor & Hodge, 1981) that may also bring about relevant epistemological consideration that have been prized in the educational scene for over two decades (e.g. Abd-El-Khalick, 2013; Allchin, 2004; Aduriz-Bravo & Izquierdo-Aymerich, 2009; Clogh & Olson 2008; Gil Perez *et al*., 2001; Lederman, 2007; Matthews, 1992).

Starting from ideas such as these, one of the authors of this paper developed a 20-hours high-school level course on the history of optics (Forato, 2009; Forato *et al*., 2012a). That module used an explicit and reflexive approach concerning the nature of science (Rudge & Howe, 2009). It also presented a revision of the laws of geometric optics and of the main optical phenomena, discussing the nature of light and the methodological procedures used by researchers in different time periods. Nineteen teaching activities and eight short texts were used to exemplify the following traits of the nature of science (Pumfrey, 1991):

- Nature does not yield sufficiently simple evidence to allow unambiguous interpretations;
- A meaningful observation is not possible without a pre-existing expectation;
- Scientific theories cannot be proven and cannot be substantiated solely from experience;
- Scientific knowledge relies heavily, but not entirely, on observation, experimental evidence, rational arguments and skepticism.
- Science is a human activity influenced by the socio-cultural context of each era.

The course addressed three main periods of the development of optics: Antiquity; the 17th century; and the early 19th century. The structure of the third component of the course, employing six 50-minutes classroom activities, was this (Forato, 2009; Forato et al., 2010):

<table>
<tr><th colspan="3">EPISODE III</th></tr>
<tr><th>CONTENT</th><th>ACTIVITIES</th><th>CLASSES</th></tr>
<tr><td>Revision of optical phenomena</td><td>1. Slides: Optical phenomena: shadows and diffraction; superposition and interference
2. Demonstration of diffraction and luminous interferences
3. Video presentation and discussion: “Dr. Quantum – double slit experiment”: 1min 45s (YouTube)</td><td>100 minutes</td></tr>
<tr><td rowspan="2">Void and the importance of ether in the wave theory
Breaking with the corpuscular tradition
Arago’s support
The corpuscularists and Fresnel’s award
Fresnel’s theory and the acceptance of the undulatory theory</td><td>4. Presentation of play, Text 8: “Ether and the nature of light”
5. Discussion: Questions about the play</td><td>100 minutes</td></tr>
<tr><td>6. Slides: Light theories and the luminiferous ether in the 19th century
7. Text 9: “Light theories and the luminiferous ether in the early 19th century”
8. Correction and discussion of questions. Summary of the episode</td><td>100 minutos</td></tr>
</table>

The application of the course was accompanied and followed by a qualitative educational research (Ericson, 1998). The data used in the investigation included video recordings of the classes and their transcriptions; written replies of the students in the educational activities and the final evaluation; and field notes of the researcher (Carvalho, 2006). The classroom results were compared to the proposed epistemological goals, evaluating the efficiency of the oral and written instructional material that was available to the students.

Results and discussion

The course produced several positive results concerning the attainment of the nature of science goals by both the students and the teacher who trained them. There was, however, an unexpected drawback, probably due to the omission of historical details and the oversimplification of the scientific and metascientific contexts of the time. When the students were asked to assess Thomas Young's contribution to the establishment of the wave theory of light, several of them replied that his ideas were not accepted by his contemporaries because he did not know mathematics.

This mistaken interpretation of Young's contribution was identified in the students' answers to some of the evaluation questions where they were asked to comment the relevance of his experiments in the overthrow of the corpuscular theory of light. Out of 29 pupils, 14 commented that Young's contribution had serious mathematical drawbacks and that, for that reason, only Fresnel's work had a decisive influence. Among the other 15 students, 5 implicitly shared the same interpretation and only one presented a response that was close to what was expected.

Of course, the instructional material did not contain the claim that Young did not know mathematics; but the course did emphasize the relevance of Fresnel's rigorous and advanced mathematical formulation as a decisive contribution for the acceptance of the wave theory of light in the early 19th century (Buchwald, 1989; Worrall, 1994). The lack of additional information about Young's contribution led the students to conclude that he was mathematically inept.

Young's mathematical ability was not a relevant topic of the course, given its epistemological aims. However, this unexpected educational outcome became a rich source of research data, suggesting that the overly simplified account of Young's scientific contribution had produced a distorted epistemological interpretation of the episode. Incidentally, this reminded us of the warning that Young's grandfather repeatedly gave to him: "A little learning is a dang'rous thing / Drink deep, or taste not the Pierian spring" (Robinson, 2006, p. 18)[1].

One of the sources of the problem was detected after a detailed analysis of the classroom activities related to this episode, that were recorded. The content of the slides used to present the overthrow of the corpuscular theory of light did not include any information about Young's mathematical knowledge, but did highlight Fresnel's deep mathematical mastery, at several points. When the teacher explained the slides to the students, she emphasized that "Thomas Young was just a physician" and she explicitly stated twice that there was a lack of mathematical basis in his work, as contrasted to Fresnel's contribution. Therefore, although the written material read by the pupils did not assert that Young did not

[1] This saying is taken from Alexander Pope's poem "An essay on criticism" (Pope, 1717, p. 82). In Greek mythology, the spring of Pieria was sacred to the Muses; it is used as a symbol of art and science.

know mathematics or that his work lacked a mathematical foundation, the teacher did conclude so, and communicated her conclusion to the students. The problem arose, therefore, at the moment described by Chevallard (1991) as internal didactic transposition.

The traditional teaching of physics strongly emphasizes the use of mathematics. This might be an additional reason why, given the omission of additional historical information, both the students and the teacher focused on the deficient mathematical approach of Young's work and forgot other scientific, metaphysical and social facets that were dealt with in the course. One should take into account that, although there was widespread acceptance of the corpuscular theory of light, Thomas Young, after studying sound waves, developed a new proposal, criticized the corpuscular theory with sound arguments, tested and argued for the wave interpretation of light. Although he did not develop a mathematical theory of diffraction and interference, he did relevant experiments and used adequate (for his time) methodological procedures to provide a foundation for his ideas.

The acceptance or denial of the wave theory of light did not depend only on the mathematical treatment of diffraction developed by Fresnel. There were many other relevant aspects. Young's and Fresnel's theories required the acceptance of a physical entity (the ether) that was beyond any possible observation. Depending on the scientific and metaphysical requirements of the time, the acceptance of an unobservable physical cause could clash with the ideals of rationality, measurability and observability in science. It is also significant that Fresnel's mathematical treatment was not restricted to diffraction (the trait we cherish at the present time) but also to the properties of the ether and its interaction with transparent bodies (a feature we do not accept today), predicting new phenomena such as the partial entrainment of the ether by moving transparent media and producing metaphysical debates (Martins, 2012; Pietrocola, 1992, 1993). The students had also been informed about the crucial support that François J. D. Arago (1786-1853) gave to Fresnel for the development and presentation of his theory to the French Academy of Sciences (Buchwald, 1989) and the relevance of Arago's prestige in the scientific community of the time (Levitt, 2000). Several examples used in the course had illustrated and stressed the relevance of the nature of science topics that were selected, such as the metaphysical, methodological and social influences in the acceptance or denial of theories (Rudge & Rowe, 2009), but the students (and the teacher) did not apply this knowledge to the situation of Young's research and the reaction of the scientific community to his work.

Before coming across the unexpected reaction of the students, the research that had been developed had already shown the difficulties related to the simplification and omission of historical information, and led to the recognition of twelve challenges in the application of an acceptable historic account (according to contemporary historiographical standards) to education. Afterwards, the work of building the didactic proposal and the instructional material of the course led to the detection of seventeen additional hindrances that should be overcome or sidestepped (Forato, 2009; Forato *et al*., 2011; 2012a; 2012b). Although the didactic material used in the course has been created after mature historiographic and pedagogic considerations, the unexpected outcome suggests that the omission of detailed information about Young's work led the students to oversimplify and to disfigure his role in the establishment of the wave theory of light, overlooking a wealth of social, methodological and metaphysical features that had been discussed during the course.

Final considerations

If we there were no schedule limits to the duration and depth of the course, we could follow Alexander's Pope recommendation: "There shallow draughts intoxicate the brain, / And drinking largely sobers us again" (Pope, 1717, p. 82). In practice, the educational use of history of science is limited by tight limitations of time, making a detailed historical approach unfeasible. On the other hand, a concise historical account may lead to a mistaken understanding of the nature of science. What can be done to overcome this difficulty?

It is always necessary to choose a partial historical account of the episodes that will be described in any educational setting; and it is impossible to predict all consequences of the inevitable omissions and simplifications. It is possible, however, to plan the use of historical episodes to convey messages about the nature of science, and to avoid some of the most common problems of the use of history of science in education.

One should not attempt to address many different characteristics of the nature of science in a single project. After choosing a few (or just one) of the epistemological messages that should be communicated to the students, it is necessary to select an adequate historical episode where that message can be made crystal clear and to pick out the relevant historic details that can help to convey that message, leaving aside other facets (however interesting in themselves) that do not contribute to the aim in view and that could distract the students or even conflict with the main point illustrated by the episode. These and other hints (Forato *et al*., 2012a, 2012b) can help one who intends using the history of science to teach about the nature of science.

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References

Abd-El-Khalick, F. (2012). Nature of science in science education: toward a coherent framework for synergistic research and development. In B. J. Fraser, K. G. Tobin & C. J. McRobbie (eds.), *Second International Handbook of Science Education* (v. 24, Part 2, pp. 1041-1060). Dordrecht: Springer.

Abd-El-Khalick, F. & Lederman, N. (2000). The influence of history of science courses on students' views of nature of science. *Journal of Research in Science Teaching* 37: 1057–1095.

Allchin, D. (2004). Pseudohistory and pseudoscience. *Science & Education* 13: 179-195.

Arduríz-Bravo, A. & Izquierdo-Aymerich, M. (2009). A research-informed instructional unit to teach the nature of science to pre-service science teachers. *Science & Education* 18: 1177-1192.

Buchwald, J. (1989). The battle between Arago and Biot over Fresnel. *Journal of Physics* 20: 109-117.

Cantor, G. N. & Hodge, M. J. S. (Eds.) (1981). *Conceptions of ether. Studies in the history of ether theories. 1740-1900*. Cambridge, London, New York: Cambridge University Press.

Carvalho, A. M. P. (2006). Uma metodologia de pesquisa para estudar os processos de ensino e aprendizagem em salas de aula. In F. M. T. Santos & I. M. Greca (orgs.), *A pesquisa em ensino de ciências no Brasil e suas metodologias* (pp. 13-48). Ijuí: Ed. Unijuí.

Chevallard, Y. (1991). *La transposición didáctica: del saber sabio al saber enseñado*. Buenos Aires: Aique.

Clough, M. & Olson, J. (2008). Teaching and assessing the nature of science: an introduction. *Science & Education* 17: 143–145.

Erickson, F. (1998). Qualitative research methods for science education. In B. Fraser & K. Tobin (Orgs.), *International Handbook of Science Education* (Part One, pp. 1155-1173). Dordrecht: Kluwer Academic Publishers.

Forato, T. C. M. (2009). *A natureza da ciência como saber escolar: um estudo de caso a partir da história da luz*. PhD Dissertation. 2 vols. São Paulo: Faculdade de Educação da Universidade de São Paulo (FEUSP).

Forato, T. C. M., Martins, R. A. & Pietrocola, M. (2010). Alguns debates históricos sobre a natureza da luz: discutindo a natureza da ciência no ensino. In: R. A. Roberto, L. Lewowics, J. M. H. Ferreira, C. C. Silva & L. A.-C. P. Martins (Orgs.), *Filosofia e história da ciência no Cone Sul. Seleção de trabalhos do 6º Encontro* (pp. 616-626). Campinas: Associação de Filosofia e História da Ciência do Cone Sul.

Forato, T. C. M., Pietrocola, M. & Martins, R. A. (2011). Historiografia e natureza da ciência na sala de aula. *Caderno Brasileiro de Ensino de Física*. Florianópolis 28 (1): 27-59.

Forato, T. C. M., Martins, R. A. & Pietrocola, M. (2012 a) History and nature of science in high school: building up parameters to guide educational materials and strategies. *Science & Education*: 21 (5): 657-682.

Forato, T. C. M., Martins, R. A. & Pietrocola, M. (2012 b). Enfrentando obstáculos na transposição didática da História da Ciência para a sala de aula. In Peduzzi, L; Martins, A; Hidalgo, J (Orgs). *Temas de História e Filosofia da Ciência no Ensino* (pp. 123-154). Natal: EdUFRN.

Gil Pérez, D., Montoro, I., Alis, J., Cachapuz, A. & Praia, J. (2001). Para uma imagem não deformada do trabalho científico. *Ciência & Educação* 7(2): 125-153.

Höttecke, D. & Silva, C. C. (2011). Why implementing history and philosophy in school science education is a challenge: an analysis of obstacles. *Science & Education* 20: 293-316.

Kragh, H. (1987). *An introduction to the historiography of science.* Cambridge: Cambridge University Press.

Kuhn, T. (1977). *The essential tension: selected studies in scientific tradition and change*. Chicago: University of Chicago Press.

Lederman, N. (2007). Nature of science: past, present, and future. *In* S. Abell & N. Lederman (Eds), *Handbook of research on science education* (pp. 831-880). Mahwah, NJ: Lawrence Erlbaum Associates.

Levitt, T. (2000). Editing out caloric: Fresnel, Arago and the meaning of light. *British Journal of the History of Science* 33 (116): 49-65.

Martins, R. A. (2006) Introdução: a história da ciência e seus usos na educação. In C. C. Silva (org.), *Estudos de história e filosofia das ciências. Subsídios para aplicação no Ensino* (pp. 3-21). São Paulo: Ed. Livraria da Física.

Martins, R. A. (2012). O éter e a óptica dos corpos em movimento: a teoria de Fresnel e as tentativas de detecção do movimento da Terra, antes dos experimentos de Michelson e Morley (1818-1880). *Caderno Brasileiro de Ensino de Física* 29 (1): 52-80.

Matthews, M. R. (1989). A role for history and philosophy in science teaching. *Interchange* 20 (2): 3-15.

Matthews, M. R. (1992). History, philosophy and science education: the present reapproachment. *Science & Education* 1: 11-47.

Nersessian, N. (1984). Aether/or: the creation of scientific concepts. *Studies in the History and Philosophy of Science* 15: 175-212.

Pietrocola, M. (1992). *Mascart et l'optique de corps en mouvement*. PhD Dissertation. Paris: Université de Paris.

Pietrocola, M. (1993) Fresnel e o arrastamento parcial do éter: a influência do movimento da Terra sobre a propagação da luz. *Caderno Catarinense de Ensino de Física* 10 (2): 157-172.

Pope, A. (1717). *Works of mister Alexander Pope*. London: W. Bowyer.

Pumfrey, S. (1991). History of science in the National Science Curriculum: A critical review of resources and their aims. *British Journal of History of Science* 24: 61-78.

Robinson, A. (2006). *The last man who knew everything*. Oxford: Oneworld.

Rudge, D. & Howe, E. (2009). An explicit and reflective approach to the use of history to promote understanding of the nature of science. *Science & Education* 18: 561-580.

Whitaker, M. A. B. (1979). History and quasi-history in physics education – part 1. *Physics Education* 14: 108-112.

Worrall, J. (1994). How to remain (reasonably) optimistic: scientific realism and the luminiferous ether. *PSA: Proceedings of the Biennial Meeting of the Philosophy of Science Association* 1: 334-342.