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REVIEW OF RESEARCH (INVITED CONTRIBUTION)
Methods and issues of teaching and learning

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TEACHING CHEMISTRY AS RHETORIC OF CONCLUSIONS OR HEURISTIC PRINCIPLES - A HISTORY AND PHILOSOPHY OF SCIENCE PERSPECTIVE

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ABSTRACT: This study has the following objectives: a) To show how the importance of history of chemistry has been recognized in the classroom, starting from the 1920s to the present; and b) How criteria based on history and philosophy of science can be used to evaluate presentation of atomic structure in general chemistry textbooks. Results obtained show that most of the new (1970-92) and old (1929-67) textbooks not only ignore the history and philosophy of science but also present experimental findings as a 'rhetoric of conclusions.' It is concluded that such presentations are not conducive towards a better understanding of scientific progress. It is suggested that history and philosophy of science can be introduced in the classroom not necessarily through formal courses in the history of chemistry or comments and anecdotes, but rather by incorporating the 'heuristic principles' that guided the scientists to elaborate their theories. [*Chem. Educ. Res. Pract. Eur.*: 2000, *1*, 315-322]

KEY WORDS: *history and philosophy of science; atomic structure; heuristic principles; rhetoric of conclusions*

INTRODUCTION

Recent research in chemistry and science education has recognized not only the importance of history and philosophy of science, HPS (Duschl, 1994; Hodson, 1988; Matthews, 1994; Moore, 1998; Niaz, 1993, Scerri, 2000), but also its implications for science textbooks (Matthews, 1994; Niaz, 1998, 1999). Rodríguez and Niaz (1999) have shown that the importance of history and philosophy of science was recognized in chemical education since the early 1920s. Most teachers in different parts of the world rely quite heavily on the textbook, as perhaps the only source of information. In the case of chemistry most students at the secondary and freshman level think that they do not have to understand chemistry but rather memorize the different concepts. Thus, it is not difficult to appreciate why students do not like chemistry. Nevertheless, the interesting point is that many freshman general chemistry courses and textbooks present material that does not call for much conceptual understanding. Siegel (1978) has emphasized the use of the history and philosophy of science if we want that science textbooks not be ". . . regarded as tools for inculcating in science students the principles and methods of the paradigm of the day. Rather, textbooks are to function as challengers to students" (p. 309). In contrast to Siegel, some educators, following Kuhn (1970), would like students to be inmersed in current paradigms, eventually providing them the background for a critical appraisal (Hodson, 1988; Lincoln, 1989).

Heuristic principles

According to Schwab (1974), scientific inquiry tends to look for patterns of change and relationships, which constitute the heuristic (explanatory) principles of our knowledge. A fresh line of scientific research has its origins not in objective facts alone but in a conception, a deliberate construction of the mind – a heuristic principle. This tells us what facts to look for in the research and what meaning to assign. Chemistry textbooks and curricula have ignored Schwab's advice, which leads to a lack of an epistemological distinction between the methodological (experimental) and interpretative (heuristic) components.

According to Schwab (1974), it is important to understand not only the experimental details but also the heuristic principle that underlies the experimental findings: "In physics, similarly, we did not know from the beginning that the properties of particles of matter are fundamental and determine the behavior of these particles, their relations to one another. It was not verified knowledge but a heuristic principle needed to structure inquiry, that led us to investigate mass and charge and, later, spin" (Schwab, 1974, p. 165).

History of structure of the atom since the late 19th and early 20th century shows that the models of J. J. Thomson, E. Rutherford, and N. Bohr evolved in quick succession and had to contend with competing models based on rival research programs (Achinstein, 1991; Falconer, 1987; Heilbron & Kuhn, 1969; Hettema, 1995; Holton, 1986; Kuhn, 1984; Lakatos, 1970; Popper, 1965).

The importance of the textbook in science education has been recognized in transmitting to the students as to how a particular science has developed (Brush, 1978; Jensen, 1998; Kuhn, 1970; McComas, Almazroa, & Clough, 1998; Siegel, 1978; Shiland, 1998; Stinner, 1992). Among other topics, atomic structure in the general chemistry program is particularly suitable for the introduction of historical details. Given this perspective it is important to analyze freshman college-level introductory chemistry textbooks to determine the degree to which they deal with recent developments in the history and philosophy of science.

This study has the following objectives:

1. A review of the literature in chemistry education to understand as to how history and philosophy of science (HPS) criteria can be incorporated in teaching atomic structure as part of the general chemistry program. Based on these criteria, results of a study (Niaz, 1998) are reviewed with respect to evaluation of textbooks published between 1970-92.
2. Evaluation of textbooks with respect to atomic structure, published between 1929-67 (Rodríguez & Niaz, 1999), based on the criteria used in the previous study (Niaz, 1998).

HOW HISTORY AND PHILOSOPHY OF SCIENCE CRITERIA CAN BE INCORPORATED IN TEACHING ATOMIC STRUCTURE

This section presents a brief review of the study by Niaz (1998) to show how criteria based on history and philosophy of science (HPS) can be used to evaluate freshman general chemistry textbooks published. All textbooks (old and new) were published in the U.S./U.K.

Criteria for the evaluation of chemistry textbooks

Based on the HPS perspective (Niaz, 1998) the following criteria were elaborated for the evaluation of freshman general chemistry textbooks:

T1 –Cathode rays as charged particles or waves in the ether. Thomson's experiments were conducted against the backdrop of a conflicting framework. Thomson (1897) explicitly points out that his experiments were conducted to clarify the controversy with regard to the nature of the cathode rays; that is, charged particles or waves in the ether. This criterion is based on: Thomson (1897); Achinstein (1991); and Falconer (1987).

T2 –Determination of mass-to-charge ratio to decide whether cathode rays were ions or a universal charge particle. Thomson decided to measure mass-to-charge ratio to identify cathode rays as ions (if the ratio was not constant) or as a universal charged particle (constant ratio for all gases). This criterion is based on: Thomson (1897); Achinstein (1991); Heilbron (1964); and Niaz (1994).

R1 –Nuclear atom. Rutherford's experiments with alpha particles and the resulting model of the nuclear atom had to compete with a rival framework, namely Thomson's model of the atom (referred to as 'plum-pudding' in most textbooks). This criterion is based on: Rutherford (1911); and Niaz (1994).

R2 –Probability of large deflections is exceedingly small as the atom is the seat of an intense electric field. The crucial detail that clinched the argument in favor of Rutherford's model was not the large angle deflection of alpha particles (an important finding), but rather the knowledge that 1 in 20,000 particles deflected through large angles. This criterion is based on Rutherford (1911); Herron (1977); and Millikan (1947).

R3 –Single or compound scattering of alpha particles. To maintain his model of the atom and to explain large angle deflections of alpha particles, Thomson put forward the hypothesis of compound scattering (multitudes of small scatterings). The rivalry between Rutherford's hypothesis of single scattering based on a single encounter and Thomson's hypothesis of compound scattering led to a bitter dispute between the proponents of the two hypotheses. This criterion is based on: Rutherford (1911); Crowther (1910); and Wilson (1983).

B1 –Paradoxical stability of the Rutherford model of the atom. Bohr's main objective was to explain the paradoxical stability of the Rutherford model of the atom, which constituted a rival framework for his own model. This criterion is based on: Bohr (1913); Lakatos (1970); and Niaz (1994).

B2 –Explanation of the hydrogen line spectrum. Bohr had not even heard of the Balmer and Paschen formulas for the hydrogen line spectrum, when he wrote the first version of his 1913 article. Failure to understand this episode within a historical perspective led to an inductivist/positivist interpretation, referred to as the "Baconian inductive ascent" by Lakatos (1970). Interestingly, Kuhn and Lakatos, in spite of their so many differences, agree that Bohr's major contribution was the quantization of the Rutherford model of the atom. This criterion is based on: Bohr (1913); Heilbron and Kuhn (1969); Lakatos (1970); and Niaz (1994).

B3 –Deep philosophical chasm. Bohr's incorporation of Planck's 'quantum of action' to the classical electrodynamics of Maxwell, represented a strange 'mixture' for many of Bohr's contemporaries and philosophers of science. This episode illustrates how scientists, when faced with difficulties, often resort to such contradictory 'grafts.' This criterion is based on: Bohr (1913); Holton (1986); Margenau (1950); and Lakatos (1970).

To refer to the criteria based on the three models, the following symbols were used: T = Thomson; R = Rutherford; and B = Bohr. The HPS perspective facilitates the understanding of these criteria (T1, T2, R1, R2, R3, B1, B2, and B3) as 'heuristic principles' (Schwab, 1962, 1974) that underlie the work of Thomson, Rutherford and Bohr.

Finally, the following classifications were generated to evaluate the textbooks:

- Satisfactory (S): Treatment of the subject in the textbook is considered to be satisfactory if the role of conflicting frameworks based on competing models of the atom is briefly described.
- Mention (M): A simple mention of the conflicting frameworks or controversy with no details.
- No mention (N): No mention of the conflicting frameworks.

RESULTS OF THE EVALUATION

Evaluation of new textbooks published between 1970-92

Of the 23 textbooks that were evaluated only two mentioned (M) that Thomson's experiments were conducted against the backdrop of a conflicting framework, namely cathode rays could have been charged particles or waves in the ether (criterion T1). Only two textbooks described satisfactorily (S) that Thomson determined mass-to-charge ratio to decide whether cathode rays were ions or a universal charged particle (criterion T2).

Seven textbooks described satisfactorily (S) that Rutherford's model of the nuclear atom had to compete with a rival framework, namely Thomson's model of the atom (criterion R1), whereas four textbooks mentioned (M) the conflict. Only two textbooks satisfactorily (S) described that the crucial argument in favor of Rutherford's model was not the large angle deflections of alpha particles but rather the knowledge that 1 in 20,000 particles deflected through large angles (criterion R2). None of the textbooks described satisfactorily (S) or mentioned (M) the rivalry between two conflicting frameworks, namely Rutherford's hypothesis of single scattering and Thomson's hypothesis of compound scattering (criterion R3).

Four textbooks mentioned (M) that Bohr's main objective was to explain the paradoxical stability of the Rutherford model of the atom, which constituted a rival framework (criterion B1), and three textbooks described it satisfactorily (S). None of the textbooks mentioned (M) or described satisfactorily (S) the quantization of the Rutherford model of the atom within a historical perspective (criterion B2). Four textbooks mentioned (M) and another two described satisfactorily (S) how scientists (Bohr in this case), when faced with difficulties, often resort to contradictory 'grafts' that represent a deep philosophical chasm (criterion B3).

To summarize, very few of the new textbooks presented the work of Thomson, Rutherford and Bohr within a historical framework and in general lacked a philosophy of science perspective. Complete details of the evaluation of new textbooks is provided by Niaz (1998).

Evaluation of old textbooks published between 1929-67

Of the 30 textbooks evaluated, 4 were published between 1929-40, 3 between 1941-50, 16 between 1951-60, and 7 between 1961-67. Both authors evaluated separately all the 30 textbooks on the 8 criteria adapted from Niaz (1998). There was complete agreement on all 8 criteria for 12 textbooks, on 7 criteria for 14 textbooks, on 6 criteria for 3 textbooks and on 5 criteria for one textbook. After discussion consensus was achieved on all disagreements.

Only one textbook mentioned (M) criterion T1, with respect to cathode rays as charged particles or waves in the ether. Criterion T2, with respect to determination of mass- to- charge ratio to decide whether cathode rays were ions or a universal charged particle, was not mentioned (N) by any textbook. With respect to criterion T2 one of the textbooks stated: "The ratio of the charge on an electron to its mass was determined in 1897 by the English physicist Sir J.J. Thomson by investigation of the behavior of beams of electrons in electric and magnetic fields. Such a calculation is possible because the extent to which a beam of electrons is deflected under these conditions depends on the charge on the electron, its mass, and the velocity with which the electron is moving. The student is referred to more advanced texts for the exact method by which the determination and calculation are made" (Sisler, Vandeerwerf, & Davidson, 1959, p. 121). This presentation ignores the fact that at the freshman level additional experimental details are not necessary. Nevertheless, a rationale as to why Thomson was trying to determine the mass-to-charge ratio, namely the underlying 'heuristic principle' could have facilitated a greater conceptual understanding for the students. Most textbooks not only did not mention the 'heuristic principle' but also presented Thomson's findings in a way that approximates to what Schwab (1962) referred to as a 'rhetoric of conclusions.' Following are some of the examples:

> "... if the [cathode] rays pass between electrically charged metal plates, their path is curved toward the positively charged plate. This is definite evidence that the rays consist of particles of matter and not a beam of light ... " (Timm, 1956, p. 76).

> "... Sir J.J. Thomson (1856-1940), an English scientist, demonstrated that cathode rays could be deviated toward a positively charged plate, indicating that the particles were negatively charged. Since cathode rays originated from the atoms of any element that was used to form the cathode, it was logically assumed that the particles were elementary constituents of all atoms" (Frey, 1965, p. 30).

> "The significance of these researches lies in the fact that these 'corpuscles,' as Sir J.J. Thomson called them, were obtained free from encumbering atoms, and were recognized as units of negative electricity: they were, indeed, the electrons of Stoney" (Caven & Lander, 1939, p. 44).

These presentations lack the appreciation that besides his experimental findings Thomson was guided by his 'heuristic principles' and it took a lot of controversy to understand the significance of these researches. It is not farfetched to suggest that such presentations lead the students to memorize the experimental details and ignore the underlying rationale for the experiment, which could facilitate conceptual understanding. Thus the theoretical rationale ('heuristic principle') in which the experiment is conducted is more important than the experiment itself (Niaz, 1999).

Criterion R1, with respect to Rutherford's nuclear atom was mentioned (M) by only one textbook. Criterion R2, with respect to probability of large deflections is exceedingly small as the atom is the seat of an intense electric field, was described satisfactorily (S) by only four textbooks, and another four textbooks mentioned (M) it. None of the textbooks described satisfactorily (S) or mentioned (M), the rivalry between two conflicting frameworks, namely Rutherford's hypothesis of single scattering and Thomson's hypothesis of compound scattering (criterion R3), put forward to explain Rutherford's alpha particle experiments. With respect to criterion R3 one of the textbooks stated: "Any deflection is a sign that something has been hit, which is comparable in mass with an alpha particle; and the only possible conclusion is that the alpha particle has encountered the nucleus of an atom, since the planetary electrons are powerless to cause an alpha particle to deviate from its rectilinear course" (Caven & Lander, 1939, p. 57, emphasis added). This presentation ignored the fact that J.J. Thomson, considered to be the world master in the design of atomic models, thought that there were other possible conclusions, which led to a bitter dispute with E. Rutherford. This example shows that the inclusion of HPS in the textbook is essential not only to facilitate conceptual understanding but also for keeping the historical record straight, which shows that progress in science is characterized by the postulation of rival models/theories.

Seven textbooks mentioned (M) that Bohr's main objective was to explain the paradoxical stability of the Rutherford model of the atom, which constituted a rival framework (criterion B1) and none described it satisfactorily (S). Only one textbook, mentioned (M) the quantization of the Rutherford model of the atom within a historical perspective (criterion B2) and none of the textbooks described it satisfactorily (S). None of the textbooks described satisfactorily (S) or mentioned (M), how scientists (Bohr in this case), when faced with difficulties, often resort to contradictory 'grafts' that represent a deep philosophical chasm (criterion B3).

CONCLUSIONS

This study shows that although the importance of history and philosophy of science was recognized since the early 1920s, in actual practice for most chemistry textbooks, it has only served as rhetoric. As the textbook is an important source of information for both students and teachers, classroom practice continues to be ahistoric (Brush, 1978; Shiland, 1998). Interestingly, starting from the 1930s most of the authors who emphasized the importance of history, also recognized the lack of adequate teaching materials and strategies. The new textbooks (published between 1970-92) have improved slightly as compared to the old textbooks (published between 1929-67). Nevertheless, both the old and new textbooks, not only ignore the history and philosophy of science (HPS) perspective, but also present experimental findings as a 'rhetoric of conclusions' (Schwab, 1962). It is concluded that such presentations in textbooks are not conducive towards a better understanding of scientific progress.

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