HOW CHEMISTRY TEACHERS, USING HISTORY OF CHEMISTRY, COULD TEACH CHEMISTRY

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Abstract: The main purpose of this paper is to show how chemistry teachers, using history of chemistry, could teach chemistry. It means something more than an undifferentiated mass of names and dates. Represents a difficult equilibrium between over-simplification versus over-elaboration and seeks to recognize the way that consolidates, in the teaching of chemistry, different entities such as atoms, molecules, electrons, spin or nanoparticles. Following the initial proposal of Jensen (1998), this paper reconstructs the history of chemistry in terms of five revolutionary moments. These moments are considered in terms of the Kuhnian notion of 'exemplar,' rather than 'paradigm.' This approach enables the incorporation of instruments, (pneumatic through, balance, kaliapparat, cathode rays tube, mass spectrometer, NMR, chromatograph, electron capture detector) as well as concepts. For educational and realism reasons these five revolutions are named after by the chemical structural entities that emerged and incorporated in the textbooks, from them: Atoms (1766-1808); Molecules and Isomers (1831-1861); Electrons and Isotopes (1897-1923); Spin (1945-1965) and Nanoparticles (1973-1999). As any chemistry teacher knows, it is from these structural entities, that chemistry (and its sub-disciplines) is taught worldwide today.

Key words: Chemistry, Revolutions, History.

INTRODUCTION

Sharing one's knowledge with the citizenry is rarely a moral imperative for chemists, as it ought to be.
Chemists, taken collectively, could not care less.
They pay dearly for their lack of interest in science communication.
This is a major cause of chemophobia,
on the part of the uninformed or misinformed public.
P. Lazlo, 2001

The way in which chemistry is taught all around the world implies a unique philosophical position which can be characterized as logical positivism (Van Berkel *et al*., 2000; Erduran & Scerri 2002; Van Aalsvoort 2004; Chamizo, 2014). Chemistry education practice has not been driven to any great extent by educational, historical, or philosophical research findings. Besides we learn about the world mainly learning about how to intervene in it. It means through technoscience (Tala, 2011) or technochemistry (Chamizo, 2013). The know-how involves learning processes of the practice whose explanation lies not only in the internalization of declarative statements and facts... so it is possible a place for the history and philosophy of sciences (or technosciences)!

The main purpose of this paper is to show how chemistry teachers, using history of chemistry, could teach chemistry. It means something more than an undifferentiated mass of names and dates. Represents a difficult equilibrium between over-simplification versus over-elaboration and seeks to recognize the way that consolidates, in the teaching of chemistry, different entities such as atoms, molecules, electrons, spin or nanoparticles. Hence, following the initial proposal of Jensen (1998), reconstructs the history of chemistry in terms of five revolutionary moments (Chamizo 2011). These moments are considered in terms of the Kuhnian notion of 'exemplar,' rather than 'paradigm.' This approach enables the incorporation of instruments (Holmes & Levere 2000), as well as concepts into the revolutionary process and provides a more adequate representation of such periods of development and consolidation (Chamizo 2014a). Moreover, accepting the premise of the 'scientific revolutions' recognizes better the continuity of scientific endeavour once the transitions are closer and less sharp. Besides agrees with Chang's (2011) idea about that historical epochs are marked out by epistemic objects (entities that we identify as constituent parts of reality) just as much as by people, institutions or theories, so where we recognize continuities and discontinuities in epistemic objects does affect our historiography in substantive ways.

This brief introduction, it's useful to defend the value of the history of chemistry (Nieto-Galan, 2010) as one of the prime locations to understand chemistry. When a community and particularly an educational community, renounces to recognize history, its own past, abdicating to know those events that should be part of the collective memory of the community, the image of the past, and why not, the present and the future is built by others.

ABOUT HISTORY OF SCIENCES

Scientific knowledge (is) primarily… a human product,
made with locally situated cultural and material resources,
rather than as simply the revelation of a pre-given order of nature
J. Golinski, 2005, p. xvii

Unlike the various Positivist approaches that dominated philosophy of science until the twentieth century, Thomas Kuhn's ideas about scientific revolutions, introducing history in philosophy of science have been widely discussed and for many scholars accepted in general terms (Kindi & Arabtzis 2012). For Kuhn, scientific revolutions are "taken to be those non-cumulative developmental episodes in which an older paradigm is replaced in whole or in part by an incompatible new one" (Kuhn 1970, p.92). This change requires a reconstruction of the historical commitments of a particular scientific community. The commitments shared by groups or communities are characterized by the use of the word 'paradigm', which means a "criterion for choosing problems that, while the paradigm is taken for granted, can be assumed to have solutions" (Kuhn 1970, p.37). Over the same historical period different scientific communities share the same paradigm and research and teaching based on this paradigm are known as "normal science". When there is a scientific revolution the community changes its paradigm, thereby changing the activities related to ‘normal science’. Normal or paradigmatic science is employed by a specific community in its daily activities, based on their previous achievements, and is what is taught in textbooks. Scientific progress in normal science is cumulative or gradual. Revolutionary science develops when a crisis occurs in normal science. The result of a revolutionary process in science is the emergence of a new paradigm, which displaces the previous one, and has traditionally been identified with changing theories. Therefore, the communities that assume different paradigms find significant difficulties in communicating with each other. Competing paradigms lack a common measure because they use different concepts and methods to address different problems -they are in Kuhn’s terminology, incommensurable.

The term 'exemplar' represents a specific historical community’s collection of solved problems and is generally found in its professional literature, and especially in its textbooks. It is narrower than paradigm and avoids some of the ambiguities that the latter has acquired. Making explicit the role of instruments in normal science reduces the gap between normal and revolutionary science. This has an important consequence, because exemplars, being more flexible and also more practically accurate than paradigms, not only recognize the conceptual or theoretical changes within a discipline, but also indicate that they are accompanied by the design, construction and use of certain instruments. In this way Davis Baird claims that: “instruments are not in the intellectual basement; they occupy the same floor as our greatest theoretical contributions to understand the world” (Baird 2004, p xvii). The use of new instruments[1] opens new territories sometimes without having any underlying theory.

Allowing for specific historiographical variations among historians, the above considerations suggest that there are at least four acceptable answers to the question “What is a scientific revolution?” According to what has been said previously, these are:

1. A radical reinterpretation of existing thought.
2. The resolution of a long-standing debate, the solution of which revolutionizes the kind of problems scientists are able to successfully attack on a routine basis.
3. The use of new instruments changes the way in which its practitioners look and work in the world.
4. The opening of a new level of theoretical understanding that subsumes older theories as special cases.

FIVE CHEMICAL REVOLUTIONS

Generally, a nonhistorical approach tends to conceal complexity.
The historical approach (of teaching chemistry) seeks to resolve complexity.
Henry A. Bent, 1971 p.129

Chemistry, as far as we know, is the result of a multitude of legacies, which specified in trades, transformed the everyday lives in all cultures. It is still surprising that practices as different as blacksmith, healer, potter or baker led to metallurgy, pharmacy, ceramics and biotechnology, and that, they integrated a common discipline, chemistry, in which it is studied, practiced and transmitted, how to transform materials.
In laboratories, spaces dedicated to practical work, rather than theoretical research, the

activities conducted there for thousands of years have been considered of less intellectual level. The Latin word *laborare* reminds us the manual labour, which was carried out by slaves in the Roman Empire. The seventeenth century English philosopher Thomas Hobbes, opponent of Robert Boyle and his famous experiments with vacuum pump[2], indicated the low status of those engaged in practical work: grocers, gardeners, blacksmiths or mechanics. Those who assumed that money (with which to buy better materials and / or equipment) could contribute to the acquisition of knowledge were wrong. Since the late antiquity and in particular since the Middle Ages, the preparation of medicines, the manufacture of soaps, pigments, glass, ceramics, explosives and metal mining were practical activities far away from the philosophical thinking, which took place in markets and public places. Skilled artisans who learnt their trade by apprenticeship imbued with different religious ideas developed these activities. However since that time the most important characteristic of a laboratory was recognized: their isolation from everyday life and the presence of apparatus and instruments. This was accomplished first with chemical laboratories that preceded physics' lab for almost two centuries. All this knowledge (alchemy, iatrochemistry etc.) with its important contribution in the development of experimental techniques is here recognized as protochemistry, which precedes actual chemical revolutions.

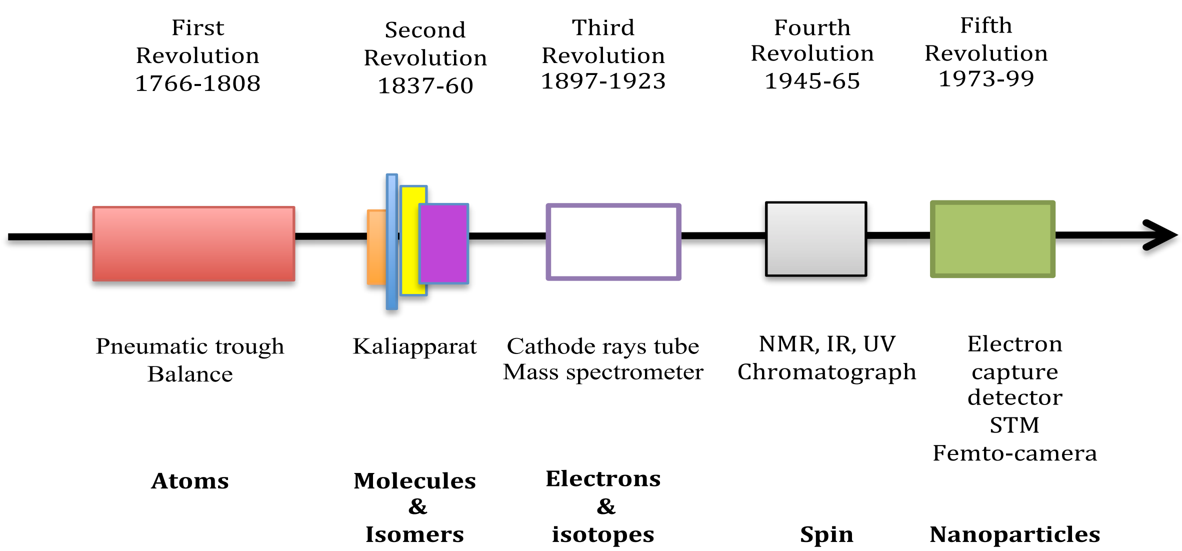

Figure 1. Instruments and entities related with the five chemical revolutions.

For educational and realism[3] reasons these five revolutions are named after by the chemical structural entities that emerged and incorporated in the textbooks, from them: Atoms (1766-

1808); Molecules and Isomers (1831-1861); Electrons and Isotopes (1897-1923); Spin (1945-1965) and Nanoparticles (1973-1999), Figure 1.

Table 1. Some characteristics of the five revolutions

REVOLUTION	PHILOSOPHICAL HIGHLIGTHS	PROTAGONISTS
FIRST (1766-1808)	Chemistry was recognized as an independent discipline with atoms as its distinctive entity.	H. Cavendish, J. Priestley A. Lavoisier, J. Dalton
SECOND (1831-1861)	Molecules, as a spatial specific atomic conglomerate with particular properties, become the *quintessential* chemistry entity. Organic chemistry emerges as a sub-discipline.	J. Liebig, S. Cannizaro L. Pasteur, A. Kekule, D. Mendeleiev
THIRD (1897-1923)	Atoms and molecules are conformed by electrons and nuclei. Those two new entities were considered fundamental in the explanation of chemical bond. Structural physical-chemistry has become one sub-discipline.	J.J. Thomson, F. Aston G.N. Lewis
FOURTH (1945-1965)	Despite the spin was known before, it is in this period that bursts significantly in chemistry. Theoretical chemistry start using computers and set as a sub-discipline in its ability to explain the chemical bond. Through NMR instruments, spin is "enthroned" in laboratories.	L. Pauling, R. Woodward[4], R. Hoffmann, A.J.P. Martin
FIFTH (1973-1999)	It is the time of organometallic, green, supra, nano and femtochemistry. "At the scale of the nanometer, it is possible to visualize and address a single molecule (nanoparticle) rather than operating at the level of N (Avogadro number) molecules…molecules, macromolecules as well as genes and proteins, are viewed as machines performing specific tasks rather than as building blocks of matter" (Bensaude-Vincent and Simon 2008 p.217).	O. Fisher, G. Wilkinson, J.E. Lovelock, E. Ruska, G. Binning, H. Rohrer[5], M. Molina, F.S. Rowland, D.J. Cram, J.A. Lehn, C.J. Pedersen, R.F. Curl, H.W. Kroto, R.E. Smalley, A. Zewail.

As any chemistry teacher knows, it is from these structural entities, that chemistry (and its sub-disciplines, Table 1) is taught worldwide today.

ABOUT THE CURRICULUM OF CHEMISTRY

The major purposes of chemical education in the 21st century
will be to introduce all young people
to the implications of chemical technologies and to provide the basis
for the advanced study of chemistry by only some of those young people.
In order to address both these purposes adequately,
the future curriculum at all levels will have to reflect,
to a far greater degree than is currently the case, trends in chemistry itself.
J. Gilbert, 2000

There are many difficulties in teaching history of chemistry. Recently, Höttecke & Celestino-Silva (2011) recognized three of them: teachers' skills, epistemological and didactical attitudes and beliefs; institutional framework of science teaching, and available textbooks. Generally speaking, scientific content is taught, but Schwab's (1962) interpretation of science teaching as a dogma or as ''a rhetoric of conclusions'' remains. Therefore, if scientific competence is not worked out, we cannot say that scientists are being trained. About this there are different positions (Allchin 2004; Chamizo 2007) but, to sum up, it is possible to recognize that scientific teaching requires more 'context' (Gilbert 2006) and reflection. I will not discuss here the importance of the history and philosophy of sciences in their teaching. It is sufficient to indicate the recent appearance of a *Handbook* specifically dedicated to it. There his editor follows (Matthews 2014 p. 7):

The expectation is that the handbook will demonstrate that History and Philosophy of Science contributes significantly to the understanding and resolution of the numerous theoretical, curricular and pedagogical questions and problems that arise in science…[and] will make the history and philosophy of science a more routine and expected part of science and mathematics teaching, teaching education and graduate research programs.

As noticed here I sustain that against this timeframe of five revolutions it is possible to teach chemistry without being an expert in the history of chemistry. It is possible to consider the old alchemy and the modern technochemistry, it is possible to mix theory, instruments and experiments (Chamizo, 2010). It is possible to teach chemical practices.

NOTES

1. In their *Instruments of Science. An Historical Encyclopedia*, Bud and Warner indicated: "Scientific instruments are central to the practice of science. All too often they have been taken for granted. Nonetheless, while most would agree that telescopes and microscopes are scientific instruments, it has probed as difficult to

establish a general definition of the category, as it has been to define science itself" (Bud & Warner 1998, p. ix).

2. Narrated from the constructivist historiography approach by Shapin & Shaffer, 2011.
3. About this Bensaude-Vincent said: "Hacking's distinction between 'realism about theories' and 'realism about entities' could thus apply to chemistry. To be sure chemists are realists. They believe in the reality of the entities, which allows them to operate in the outside world or to be affected by it" (Bensaude-Vincent 2008, p. 52).
4. Besides the generalized introduction to analytical equipment, organic synthesis grows a lot. R. Woodward (Nobel Prize in Chemistry in 1965) took 11years, with hundreds of collaborators to synthesize vitamin B_{12} (9* C), announced in Delhi in 1972. He is considered to be the preeminent organic chemist of the twentieth century having made many key contributions to the subject, especially in the synthesis of complex natural products (quinine, cholesterol, cortisone, strychnine, lysergic acid) and the determination of their molecular structure using exhaustively UV, IR and NMR instruments. With R. Hoffmann performed theoretical studies of chemical reactions.
5. This revolution started with the Nobel Prize recognition of organometallic-chemistry, followed by the contribution of other Nobel Prize winners related with green-chemistry, nano-chemistry, supramolecular-chemistry and femto-chemistry. The electron capture detector and STM were the instruments behind this revolution.

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