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Teaching Modern Chemistry through 'Recurrent Historical Teaching Models'

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Abstract. Today there are little more of 3 million chemist all over the world producing about 800,000 papers a year. They produce new substances – from some hundreds in 1800 to about 20 million now – the vast majority artificial. This rate is growing quite fast. Once the majority of chemistry teachers all over the world used textbooks as the main (sometimes the only) source of information, we became, without wanting to... *history teachers*! If 'scientific literacy' is the aim of science lessons in school, it is much more than the literacy now developed in science classrooms. It must include an understanding of the nature and process by which scientific activities are carried out. Recognition of the exponentially chemistry knowledge growth and the incompleteness of the current chemistry textbooks are thus intimately related to recognition of the need for recurrent historical teaching models.

Key words: Chemical information growth, history teachers, recurrent historical teaching model

1. Introduction

In recent years growing evidence based on research for the inclusion of the history of chemistry in the chemistry curriculum has been produced (Duschl 1994; Matthews 1994; Jensen 1998; Wandersee & Griffard 2002) but only few examples of their implementation have been published (Allchin 1997; Wandersee & Roach 1998; Chamizo 2001).

As Wandersee (2002) concluded:

> Perhaps the greatest obstacle to incorporating history into chemistry lessons is convenient access by practising teachers to resources that can efficiently teach them the salient history behind scientist and their discoveries. Making an accurate history of chemistry more accessible to teachers is difficult to achieve. A faithful distillation of an admittedly complex history of events or a succession of models into a memorable form and in a suitable grain size for use by practising teachers is a formidable challenge.

Although history has captured the interest of chemists, the philosophy of chemistry has not received as much attention (Scerri 2000). Nevertheless, the way in which chemistry is taught implies a unique philosophical position, and generally this position is logical positivism (Erduran & Scerri 2002; Van Aalsvoort 2004). In agreement, Driver (2000) says:

> The positivist view of science, placing as it does emphasis on factual recall with confirmatory experiments, denies the role of the historical and social accounts of science, presenting science as a linear succession of successful discoveries.

In this paper I will try to show that a different approach is possible. An approach that avoids logical positivism as the main philosophical posture and in which the overall curriculum is organized from an historical viewpoint.

2. Chemistry and history

> The subject of chemistry is vast. It covers virtually all aspects of the behaviour of atoms and molecules – from the creation of the elements in the stars to the complex molecules of life. Chemistry, however, is more much than just about investigating the Universe at the molecular level; its central remit (which is quite different from those of other disciplines) is to synthesize new forms of matter, many of which are extremely useful, for example, pharmaceuticals.

With these words Nina Hall (2000) introduced the book *New Chemistry* with the aim of illustrating some of the most important research over the last 30 years. The authors are some of the world's most renowned chemists (including several Nobel Prize winners) and, as she suggested, most of them look modern chemistry through the idea of making new molecules.

What has happened with chemistry research in the last 30 years? A different answer comes from scientometrics. This is one of the different methods used in the study of the development of science. With some theoretical limitations scientometrics gives an ample image of scientific work. However, particularly in the study of modern science, it is an effective indicator of its tendencies of growth. Here I will introduce some results from this historiographic approach.

Based on the number of authors of publications taken from *Chemical Abstracts* today there are little more than 3 million chemists all over the world writing about 1,250,000 documents (papers, books and patents) a year (Chemical Abstract Service, 2005). They produce, as Hall already indicated, new substances, most of which are artificial. As Schummer (1997, 1999) showed:

> The number of known substances has been growing exponentially since 1800, from some hundreds then to about 19 million today. Since the number constantly doubles every 13 years during the whole period, it is not a bad estimate saying that we will have nearly 80 million substances in 2025.

Chemical Abstract is a database that includes around 8,000 publications of chemistry, biochemistry and chemical engineering, elaborated by Chemical Abstracts Service of the United States. It is used as the main source of information in chemistry. This database has limitations since it depends (like all the others) on the methodological characteristics of the programs to recover information; on the criteria of selection of documents to be included; and on the representativeness of its content on the set of the universe defined previously. However, today it has no rival as regards chemical information all around the world.

Chemistry teachers generally ignored that chemistry is, among all other sciences, the most productive (Tague et al. 1981). The growth of chemical information in the last century has been outstanding. For example, last year to be up-to-date in all areas of chemistry a chemist would currently have to read a little more than 3,000 new documents every day or 260 pages a day of short abstracts (Table 1). Of course, nobody is capable of reading all publications on chemistry, not even all publications in a small area like, for example, organometallic or theoretical chemistry (only 1% means 30 documents per day every day!) Thus, being up-to-date, *being universally informed has become a mere fiction for many decades*.

As last column of Table 1 shows in the last 5 years more than 3 million abstracts from the same number of primary sources of information (papers, books and patents) have been reported, almost the same quantity (as a matter of fact less) produced in the first half of the 20th century.

Table 1. Growing of chemical information. Number of abstracts included in *Chemical Abstracts* since it began

Year	Number of abstracts			Pages of abstracts	Total abstracts to date
	Papers	Books	Total		
1907	7,994	–	11,847	3,074	11,847
1910	13, 006	785	17,545	3,314	60,020
1920	13 619	1 275	19 326	3 826	256 122
1930	32,731	1,169	55,146	6,066	586,029
1940	40,624	1,421	53,680	4,170	1,206,377
1950	47,496	1,539	59,098	5,592	1,662,559
1960	104,484	2,096	134,255	13,014	2,613,069
1970	230,902	2,728	276,674	23,792	4,712,125
1980	407,342	6,399	475,739	38,188	8,544,440
1990	394,945	3,490	489,517	41,097	13,226,889
2000	573,469	5,136	725,195	74,245	19,754,207
2004	685,896	5,601	865,066	95,138	22,993,118

Looking further backwards the situation was completely different at the beginning of the 19th century when there was no difference between *handbooks* and *textbooks* at university. The necessity for textbooks came from the immense growth of the extent of handbooks. Schummer (1999) again:

> The immense production of chemistry information has considerably changed the whole system. First of all, primary sources of information, i.e. chemistry journals, have lost their former significance in favour of secondary sources, i.e. searchable databases. Beside a few leading journals in each area, which attract readers mainly by review articles, the vast majority of chemistry journals are noticed today only indirectly through the filter of databases. To be sure, secondary sources have a longstanding tradition in chemistry in the form of handbooks, most notable the handbooks of Gmelin (since 1817) and Beilstein (since 1880). But the role of secondary sources has gradually changed. Formerly mainly intended to provide surveys and references, secondary sources have today become the proper information source in the form of electronic databases.

The growth in scientific knowledge in all areas is fast. New technology is also expanding rapidly. Although it took 20 years for telephones to be owned by a million people (in the USA), it has only taken three years for personal computers to reach this level of ownership. In 2004 almost half of the total population of the worlds top 10 countries in personal computer users, had one. Therefore now in the age of computers the challenge is not only quantitative (like the change from textbooks to handbooks in the 19th century, or in the reading capacity of chemist who required to double it within the next 15 years) but also qualitative. New capacities such as switching from browsing to searching make a substantial difference in information access for users. Searching through a database requires previous knowledge of what you are looking for.

In a recent report from the National Research Council appears (Breslow et al. 2003):

> The most distinctive aspect of the chemical sciences and engineering is the ability to create new molecules and chemical systems—from minute to commodity quantities—without being limited to the study of those that already exist in nature...The promise of better medicines and better materials depends on the ability of synthetic chemists to create new transformations and to use them in the creation and manufacture of new substances. It is no surprise that synthesis is still the active concern of a large fraction of practicing chemists, and will remain so.

> The development and implementation of techniques will be critical for all aspects of chemical manufacturing – from synthesis and analysis to optimization, evaluation, design, control, supply-chain management scheduling, and operation of chemical process systems. This will need to be done in a way that is consistent with societal and economic objectives and constraints.... These constraints will require the further creation and exploitation of a science base that includes novel representations of the underlying chemical and physical phenomena.

The growing amount of information related to chemistry is making it difficult to decide what should be included in education, not only as preparatory training for future chemists, but also for the general public. When chemistry students (from secondary to undergraduate) do not know simple things about the world around them, but can regurgitate isolated facts without any discrimination whatsoever, something is wrong in chemistry education. Besides, the world around students is changing and changing quite fast. Plastics that conduct electricity, liquid crystals in sharp TV screens, lithium batteries in mobile phones, foods from genetic engineering and AIDS are only some examples. As Gabel (2002) indicated:

> Students need to understand that atoms and molecules are important, not for their own sake, but because they are used as explanations and predictions about how the physical world operates. They need to connect phenomena with the particulate nature of matter and the symbols representing the particles in order to truly understand not only chemistry but also the role of models in science and the nature of science.

Unfortunately chemistry education practice has not been driven to any great extent by research findings (for example, common misconceptions or modeling) or to accomplish professional ideals. The changes that have occurred in the majority of textbooks during the past three decades do not show any real recognition of the growth in scientific knowledge (an outstanding exception of this major trend, is the book of Royal Society of Chemistry (RSC 2000) *Cutting Edge Chemistry*). Furthermore many people believe that the contents of science textbooks are, in fact, science. This is not necessarily true. Many of the written materials employed in science education are descriptions of past science explorations (Yager 2004).

Besides all this, once the majority of chemistry teachers all over the world use textbooks as the main (sometimes the only) source of information, (it means the contents of the books expanded in an idealized attempt to cope with the increase in information and references to the history of chemistry disappeared), we became, paradoxically and without wanting to... *history teachers!*

3. Chemistry and education

Recent research in school chemistry curricula suggested that an underlying, coherent structure of chemical concepts that students are supposed to learn for the purposes of explaining and predicting chemical phenomena was almost universal (De Vos et al. 1994). The authors analyzed current and post-war textbooks and syllabi representative of secondary chemistry education in most Western countries trying to find why they are so remarkably similar.

Using Kuhn's (1970) theory of normal science and scientific training they interpreted dominant school chemistry as a form of normal science education (NSE). The latter has the following characteristics:

(a) NSE prepares future scientists for normal science.
(b) NSE is the dominant and normal form of science education in the natural sciences at the tertiary as well as at the secondary level, which means that NSE is paradigmatic.
(c) NSE contains implicit norms with respect to science and its philosophy and pedagogy.

With these ideas, they summarized in 10 statements the general nature of school chemistry and tried to validate them with an International Forum of 28 experts in chemical education (Table 2). After several years of discussion, a general agreement on the ten statements was obtained and the results of the research published (Van Berkel et al. 2000).

The conclusions of van Berkel's research, related to the International Forum of experts' discussion were:

> Normal chemistry education fails to realize its own goals, that is, teaching and learning (for all pupils) the prediction and explanation of chemical phenomena; instead it teaches/learns a set of propositions and algorithms. Neither the effectiveness of normal chemistry education nor its superiority over more critical forms of secondary chemistry education has been conclusively demonstrated. It is not possible to justify, by argument or experiment, a normal science education based course that is suitable for all pupils. Maybe this can be done with regard to the small minority of students who will study chemistry at a further level, some of whom might become chemists. Normal chemistry education cannot be regarded as a form of chemistry education

Table 2. Some of the final consensus statements related with normal school chemistry

1	All school chemistry curricula belonging to the dominant version are being taught and learned as *propositions and algorithms* to students seen as future chemists.
2	All *current* school chemistry curricula belonging to the dominant version have a *corpuscular theoretical* focus on chemical substances and their properties.
3	All current school chemistry curricula belonging to the dominant version deal with the explanation and systematization of chemical information largely in terms of *corpuscular theory*.
8	All *current* school chemistry curricula belonging to the dominant version make a distinction between a level of *phenomena* and a level of *corpuscula*. The introduction of corpuscular theory in books and classrooms is neither consistent nor accurate, and hence not effective.
9	All *current* school chemistry curricula have a dominant substantive structure, based on *corpuscular theory*, which is *rigidly* combined with a specific philosophical structure, *educational positivism*, and a specific pedagogical structure, *initiatory* and *preparatory training* of future chemists.

> appropriate for all pupils, exactly because it consists of a dogmatic, domain-specific training for future chemists.
>
> Therefore, at the secondary level, the initiation into normal chemistry should be largely replaced by an education in or through fluid, critical or revolutionary chemistry (HPS-education, Matthews 1994) together with an education in or about the relations between chemistry, technology and society (STS-education, Solomon & Aikenhead 1994).

This 'manifesto' against traditional chemistry education agrees in one way or another with other research results from different countries (Table 3).

Related to the previous results some of the recommendations of the British report *Beyond 2000: Science Education for the future* (Millar & Osborne 1999) was:

> The heart of the cultural contribution of science...a set of major ideas about the material world and how it behaves...(presented in) one of the world's most powerful and persuasive ways of communicating ideas...narrative form. It is these accounts..., which interest and engage pupils.
>
> ...work should be undertaken to explore how aspects of technology and the application of science currently omitted could be incorporated within a science curriculum designed to enhance 'scientific literacy'

As said before, Normal Chemistry Education has not been driven to any great extent by research findings. Just recently J. Moore editor of the influential *Journal of Chemical Education* (2005), indicated the poor impact of this area on teaching and learning. For example, besides the huge, and now old, results about misconceptions in chemistry education (Barker 2000), only a few incorporate their findings in textbooks as classroom resources (Taber 2002). Also, research-based evidence about misconceptions indicates that students' earliest experiences of chemistry have very significant and far-reaching effects. Students find it very difficult to unlearn an idea.

Furthermore (Gilbert et al. 2002):

> 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.

From all the previous results the challenge for teachers is therefore to develop ways of teaching the chemistry we really want them (the students) to know right from the beginning. One way which can provide a valuable link among new scientific research, technology, every day applications and education, including results from misconceptions, is through the construction of 'explanatory stories' using models and modeling.

4. History and education

The importance of models and modeling in science education has been recognized with an increasing amount of research attention. Only a few months ago Coll & Taylor (2005) recognizes:

Table 3. New goals and difficulties for scientific education

• Gabel showed (1999) that chemistry instruction that uses unfamiliar materials uses language that is defined differently in science than in everyday situations, and is structured according to the structure of the discipline as it may make learning difficult. These drawbacks to learning can be explained using the information-processing model. Students do not integrate the threefold representation of matter (macroscopic, particulate, and symbolic levels) in their long-term memory. She is trying to reform chemistry education through new programs that are based on making chemistry relevant through problem solving and collaborative learning.
• In her 'Epistemological Foundations of School Science' Izquierdo & Adúriz (2003) maintains that school science should integrate its own values with those of health, consumer and environmental education, and education for peace. School science has been formulated in a global and rather utopian framework, which is always there, in one way or another, in liberal education. What may give value to school science is having goals that students may call their own, which conform to their expectations and beliefs about school and about the 'real world' while being coherent with the science curriculum.
• From the theory model and the empirical cycle of logical positivism, Van Aalsvoort (2004) argued that knowledge is universal, objective, logical, descriptive, and theoretical. The afore-mentioned shows that chemical education intends to provide our students with the best knowledge that is available. The goal is to raise our youth to be the best imaginable individuals and to attain the best imaginable society. Despite this, its relevance is being questioned and criticized. Logical positivism, on which chemical education is currently modeled, emphasizes a conception of knowledge and holds assumptions about society and citizenship, which turns it into a counterproductive undertaking when it comes to convincing our students of the relevance of chemistry.
• Hodson (2003) published another 'manifesto' against normal science education. For him science and technology education have the responsibility of showing students the complex but intimate relationship among the technological products we consume, the process that produces them, the values that underpin them and the biosphere that sustains us. He proposed a politicized, issues-based curriculum focused on seven areas of concern (human health, food and agriculture, land, water and mineral resources, energy resources and consumption, industry, information transfer and transportation, ethics and social responsibility) and addressed at four levels of sophistication, culminating in preparation for sociopolitical action. Education for sociopolitical action entails recognizing that the environment is not just 'a given', but a social construct.

> As soon as scientists attempt to explain macroscopic nature (e.g. physical and chemical properties of substances, chemical behaviour) they inevitably resort to the use of models. Thus, models and modeling are key features of science and consequently of science education when there is an attempt to make accessible scientist' understanding and to provide some insight into their business.

It is possible to say that understanding science is to understand the models used by scientists (Harrison & Treagust 1996). In chemistry more than 25 years ago, the book by Suckling et al. (1978) *Chemistry through models* opened the field and was followed by relevant papers in chemical education (Carr 1984; Grossligth et al. 1991; Erduran & Duschl 2004).

Only recently, in education literature, a *consensus model* has been characterized when different social groups, after discussion and experimentation, can come to an agreement (Gilbert 2000). When this model has gained acceptance by a community of scientists following formal experimental testing, as manifested by its publication in a referred journal, it becomes a *scientific model*. Those consensus models produced in specific historical contexts and later superseded for many research purposes are known as *historical models*. Merging some characteristics of each of several distinct scientific and historical models forms a *hybrid model*. It is used for classroom teaching purposes as if it were a coherent whole. They appear frequently in many chemistry textbooks and as Justi (2000) showed they must be avoided.

> The identification of hybrid models provides a new insight through which teaching can be discussed. The existence of hybrid models in teaching means that no history of science is possible because it implies that scientific knowledge grows linearly and is context independent. It leads students to have misconceptions in their mental models of the theme being discussed and/or to have difficulties in understanding the reasons for which hybrid relationships are introduced.

A *teaching model* is a specially constructed model, understood by students, which explains the world around them, and acts empirically. As previously said, these are generally hybrid models which have introduced incorrect aspects of historical models and furthermore are not accompanied by any discussion of their limitations (Justi & Gilbert 2002).

Kragh (1987) recognizes at least three different approaches to history of science, three historiographical strategies: *diachronic, anachronic*, and *recurrent*. The *diachronical* ideal is to study the science of the past in the light of the situation and the views that actually existed in the past; in other words to disregard all later occurrences that could not have had any influence on the period in question. So, ideally, in the diachronical perspective one imagines oneself to be an observer in the past, not just of the past. According to the *anachronical* view, the science of the past ought to be studied in the light of the knowledge that we have today. Here the subject matter of history of science is the same as the subject matter of science.

Accordingly, science becomes a phenomenon that is bound to make progress in the direction of truth. The diachronic historiography is only an ideal. The historian cannot live separately from the times they live in or to completely avoid the use of contemporary patterns of thought. For that reason if modern patterns of rationality at the time of evaluating the historical events are used, surely we will be taken to anachronism. In this sense, Tosh (2003) argued that the history of science is inherently 'present-centered': its boundaries are determined, partly, by judgments inaccessible to the historical actors.

The history of science is not a relation between two parts, the historian and the past, but a relation among three, the past, the historian and the audience, being our students. Hence for teaching purposes (Izquierdo et al. 1999) I adopt the recurrent model.

A few years ago the French philosopher Gaston Bachelard introduced 'recurrent history of science' as one which is continually retold in the light of the present (Bachelard 1972). The aim of recurrent history is not to find our concepts already formed at some point in the past, but to reveal the way by which our concepts emerged from other concepts by a sequence of corrections or 'rectifications'. When a new concept 'appears' it introduces a reorganization of the field of study and an evaluation of the cognitive value of previously acquired knowledge. From this point of view science is therefore 'compelled' periodically to evaluate the achievements of its past. As Tiles (1984) indicated:

> It is designed to show not merely how we came to the present views but also why; it reveals the reasons for rejecting previous theories, for modifying previous concepts, and thus the reason behind the acceptance of currently accepted views.
>
> These reasons are not psychological, sociological or political. The explanation offered is not historical in that sense. 'Reason' here means a rational ground. The reasoning, which has led to presently accepted views, is therefore regarded as an important part of understanding these views, of knowing what they are. They are not only past reasons; they form part of the present justification for our theoretical positions. They are active in the present via the history of science and must be understood and subjected to critical scrutiny if further progress is to be made.

Recurrent model rational reconstruction is different from Lakatos's (1978) proposal whose rational reconstructions are how history should, conceptually, be judged by reference to some other absolute, extra historical standard of rationality. In this sense it is closer to Toulmin's (1972) approach of rationality:

> Questions of "rationality" are concerned, precisely, not with the particular intellectual doctrines that a man – or professional group – adopts at any given time, but rather with the conditions on which, and the manner in which, he is prepared to criticize and change those doctrines as time goes on...the intellectual content of any rational

> activity forms neither a single logical system, nor a temporal sequence of such systems. Rather, it is an intellectual enterprise whose "rationality" lies in the procedures governing its historical development and evolution"

A recurrent history model operates by distinguishing the 'sanctioned' from the 'lapsed'. The latter is the history of false paths, of errors and illusions, of prejudice and mystification, whereas the first one is the history of the thoughts that continue being present or that could become present if they are evaluated according to the science of the present time. Since a recurrent history model addresses the problem of error, it contributes to understanding the nature of scientific justification, as well as its limits. Knowledge has been transformed from fact into error by a sequence of rectifications. However it is necessary to be cautious about that. Ideally the old ideas are to be understood in their own terms, disciplines have their own rules and aims; the past must not be subordinated to the present. In this sense, an evaluative history of science is not just a reconstructive tracing of the route of discovery; it is also a justificatory analysis. Recurrent history helps us to understand, first the context in which 'wrong' ideas were once considered 'right', and second how (and why) such context changed. In Bachelard words (1978):

> The scientific spirit is essentially a rectification of knowledge, a widening of the framework of knowledge. It judges its past history by condemning it...Scientifically, one thinks of the truth as historical rectification of a longstanding error, one thinks of experience as rectification of an initial common illusion. The whole of the intellectual life of science plays dialectically on this differential of knowledge, at the frontier of the unknown. The very essence of reflection is to understand what one has not understood.

Thus, in recurrent historical models, rational reconstructions include objects, facts and ideas studied as well as people around them, people who assess them. They have to do with an appreciation of the kinds of problems that a model was designed to solve (Toulmin 1972), the extent to which it does so, and the reasons why, if it is correct, previous attempts were not successful and therefore had to be altered or abandoned. Such reasons do not guarantee the suitability or 'fitness' of models with the real world (Giere 1990) but they are taken as reasons for thinking that progress has been made. The main subjects for the design of a recurrent historical teaching model are exemplified below (Chamizo 2005).

4.1. THE LEWIS–LANGMUIR–SIDGWICK ATOMIC MODEL

In 1916 the American chemist G.N. Lewis (1916) presented his first paper on valency and electron structure at the Franklin Institute in Philadelphia. He based his work on the octet concept and proceeded to develop a static atomic model to illustrate the eight outer electrons. In this model (Table 4) the concept of covalency was born. Lewis has been described as possessing a stimulating spirit of inquiry and engaging in intense and diverse scientific activity. In his laboratory in Berkeley trained hundreds of future chemistry researchers some of them Nobel laureates.

Working in the Research Laboratory of General Electric, another American chemist, I. Langmuir, stimulated by Lewis paper about the cubical atom, extended and refined the basic concepts related to chemical valency (Chamizo & Gutierrez 2004). For him (Langmuir 1919):

> The problem of the structure of atoms has been attacked mainly by physicists who have given little consideration to the chemical properties, which must ultimately be explained by a theory of atomic structure. The vast story of knowledge of chemical properties and relationships, such as is summarized by the Periodic Table, should serve as a better foundation for a theory of atomic structure than the relatively meager experimental data along purely physical lines.

Langmuir (1932's Chemistry Nobel Prize laureate by his research in surfaces), considers elements with more than eight electrons which occupy small cells within concentric spherical layers, within which they could rotate, oscillate, or be fixed in some particular position. He proposed the existence of a ''quantum force'' to counterbalance Coulombic attraction. The layers are of equal thickness, reason why their radii are in relation 1:2:3:4 and its areas like $1:2^2:3^2:4^2$, that is, 1:4:9:16 are to say the double of these numbers (2,8,18,32) corresponds exactly to the regularity in the atomic number of noble gases. Langmuir designed a periodic table which

Table 4. The Lewis Cubical Atom postulates

1. In every atom is an essential *kernel* which remains unaltered in ordinary chemical changes and which possesses an excess of positive charges corresponding in number to the ordinal number of the group in the periodic table to which the element belongs.
2. The atom is composed of the kernel and an *outer atom* or *shell*, which in the case of the neutral atom, contains negative electrons equal in number to the excess of positive charges of the kernel, but the number of electrons in the shell may vary during chemical change between 0 and 8.
3. The atom tends to hold an even number of electrons in the shell and especially to hold eight electrons which are normally arranged symmetrically at the eight corners of a cube.
4. Two atomic shells are mutually interpenetrable.
5. Electrons may ordinarily pass with readiness from one position in the outer shell to another. Nevertheless they are held in position by more or less rigid constraints, and these positions and the magnitude of the constraints are determined by the nature of the atom and of such other atoms as are combined with it.
6. Electric forces between particles which are very close together do not obey the simple law of inverse squares which holds at greater distances.

shows how the electrons are occupying the different layers and in where the transition elements can naturally be allocated.

In 1927, after the work developed by 1913 Nobel Prize winner A. Werner about coordination compounds (James 1993), the English chemist N.V. Sidgwick formalizes the work of Langmuir in the denominated Effective Atomic Number (EAN or also 18 electrons rule), in which the compounds of transition elements acquire an electronic configuration with this amount of electrons, to similarity of the eight electrons required by Lewis in compounds of the main group elements. More precisely EAN suggested that electron pairs from ligands were added until the central metal was surrounded by the same number of electrons as the next noble gas. About Sidgwick style in Oxford, Laidler (1998) comments:

> Sidgwick did not do anything highly original, but he followed the work of Lewis and Langmuir; his important contribution was to use it to explain chemical behaviour. His detailed knowledge of the facts of chemistry put him in a unique position to apply the electronic theories to a wide range of chemical compounds. His work led to his book *The Electronic Theory of Valence*, which appeared in 1927, when he was, fifty-four. The book was soon recognized to be a scientific classic. In it Sidgwick skilfully and lucidly gave a fresh unity to the whole of chemistry, which for the most part had been presented as a large collection of isolated facts.

The acceptance of the octet rule (from the cubical model, an *historical* model) and of the so called Lewis structures, when Lewis (1923) published his major work on chemical bonding, was practically immediate, largely because of their capacity to explain many of the results of the then "new" physical organic chemistry, a child of the 20th century (Lowry & Richardson 1987), and the valence concept (as the number of electron pairs that an atom shared with one or more atoms, Chamizo & Gutierrez 2004). As Bunnet indicated (1996):

> The intellectual foundation of physical organic chemistry, as it developed under Ingold's leadership, was G.N. Lewis' recognition, in 1916, that a covalent bond consists of a pair of electrons shared between the atoms joined by that bond. Acceptance of his ideas was slow, no doubt in part because Berkley (Lewis home) was then two weeks in travel time distant from England, where Ingold and the other principal founders of the field were located. At an influential 1923 Faraday Society discussion, Lewis apparently convinced a number of other participants of the validity of his concepts in his role as lead-off speaker and perhaps as well in informal discussions at that meeting. His book on chemical bonding (1923) gave guidance and inspiration to all persons seriously interested in organic mechanism and reactivity.

In their own pre-quantum characteristics the possibility of expanding its limited capacity of explanation of some of the main group elements compounds, means the very well known exceptions: octet expansion, odd-electron molecules, noble gases compounds, and electron deficient compounds (Huheey et al. 1993) were more a research ambition (for example Linnett's double quartet model; Linnett 1961) than an obstacle. Its success in organic chemistry was unambiguous. For example in their sixth edition Morrison & Boyd (1992) arguing about the size increase of their textbook says: *The cornerstone of this framework has been, as always, the premise on which the science of organic chemistry rests: that chemical behaviour is determined by molecular structure*. The same happened with the new biochemistry (rooted mainly in organic macromolecules when the elements C, N and O obey strictly the octet rule) (Lehninger et al. 1993).

In contrast the Lewis–Langmuir–Sidgwick (LLS) atomic model remained forgotten until the resurgence of organometallic chemistry in the 1970's. Perhaps the significant number of exceptions where the EAN is not that of a noble gas was the main reason (largely in coordination compounds where the ligands atoms have higher electronegativity values, or when the central atom are a rare earth metal). In 1973 the development of the transition metal "sandwich" compounds known as metallocenes, gave the Chemistry Nobel Prize to E.O. Fisher and G. Wilkinson (James 1993). The structure and properties of metallocenes can be easily explained with this model.

Briefly the Atomic Effective Number, which can be set up as new postulate in Table 4 (Purcell & Kotz 1977) like: stable organometallic compounds of transition elements have a total of 18 electrons around the atom of the transition metal or the same atomic effective number of the next noble gas. Tolman (1972) proposed another postulate related with the reactivity of these compounds: *organometallic reactions, including catalytic ones, proceed by elementary steps involving only intermediates with 16 or 18 metal valence electrons*. He concluded his paper with this statement:

> The 16 and 18 electron rule in organometallic chemistry is consistent with such a large body of experimental evidence, including studies on reaction mechanisms, that anyone proposing an exceptional compound or reaction path must bear the burden of proof.

The application of these two postulates in the structure explanation of many organometallic compounds (from simple ones to complex cluster molecules), and also in their reactivity is now a normal subject in inorganic chemistry textbooks (Purcell & Kotz 1977; Greenwood & Earnshaw 1997; Mingos 1998). A useful bridge between main elements and transition elements compounds under the LLS model denominated "electronically equivalent groups" has been successfully used in chemical education (Ellis 1976).

As Mingos (1998) explained under the more complex quantum model approach.

> The EAN rule is hugely important in much transition metal chemistry and especially those compounds with π-acceptor ligands and with metal–metal bonds. The compounds are thermodynamically stable because they are fully utilizing their orbitals in the σ-bonding framework and in back donation to suitable low-lying orbitals on the ligands. In addition

> the resulting large energy gap between the highest occupied molecular orbital and the lowest unoccupied orbital makes these compounds also kinetically inert.

The LLS model has limitations (another one is related to the explanation of rare earth compounds) which the quantum-mechanical model, through their different approaches, can explain. Since the third decade of the last century the rise of Pauling's valence-bond model and Mulliken's molecular orbital model have eclipsed the utility of Lewis and LLS models as a teaching tool. In this sense Purser indicated (1999):

> Because of the tremendous predictive power of appropriate Lewis structures, care must be taken when deciding how to teach Lewis structures in general chemistry. Calculating quantum mechanical solutions to answer questions about electronic structure requires a level of sophistication usually beyond general chemistry and is reserved often for physical chemistry courses. Lewis structures, by contrast, are simple to draw, and there is no shortage of methods for obtaining good structures ...The decision of whether to teach the molecular orbital model in general chemistry must be based on the goals of the course and the level of understanding expected of the students.

Based on the main subjects that I have presented the following research questions appear:

1. Transform Lewis cubic atomic model and LLS model into a recurrent historical teaching model. It means that we can use the same arguments (octet rule, EAN rule, and also electronically equivalent groups) to explain the structure and reactivity of as many organic, inorganic, organometallic and biological molecules. This must be done to different age levels, keeping in mind the appearance of new molecules.
2. Under the historical comparison with the real world identified their capabilities and limitations. Students' misconceptions are quite useful for this purpose.
3. Through their historical limitations, generally a scientific dispute, recognize the "mistakes" or wrong ideas underlying the model.

5. Chemistry, History and Education

In present chemistry education, history plays a fundamental role. We, as history teachers, must be aware that when teaching chemistry (Husbands 2003):

> We need to establish a more subtle, less absolutist understanding of the way in which knowledge is created. Our knowledge of the world and the language with which we describe it is not simply in our own heads, nor is it a given feature of the world in which we are living. It needs to be developed through the process of inquiry in classroom, by teachers and learners in classrooms working to create meanings. Historical enquiry is not to be cut off from personal experience, nor is to be locked into personal experience. It is fundamentally a way of relating the internal, the personal to the external, the public.

As Table 3 showed we are living in changing times that urgently need a different teacher's attitude, knowledge, and didactic strategies (Matthews 1994). If 'scientific literacy' is the aim (Millar & Osborne 1999) it is much more than the literacy now developed in science classrooms. It must include an understanding of the nature and process by which scientific activities are carried out. Recognition of the exponential growth in chemistry knowledge and the incompleteness of the current chemistry textbooks are thus intimately related to recognition of the need for recurrent historical teaching models. Recurrent historical model-based teaching and learning can provide a framework for understanding the nature of the interaction between different modes of representation and the procedures of scientists themselves. Here the past is evaluated in the light of the present and at the same time that evaluative story contributes to present thought and to understand it. As Allchin (2000) indicated:

> The exploration of "wrong" ideas is potentially far-reaching. For example, some educators would banish astrology, alchemy, phrenology, craniology, mesmerism, etc., from the science classroom because they represent mistakes of science. Some contend that even mentioning such "unscientific" or "pseudoscientific" practices gives them unwarranted credence. Historically, of course, each of these practices was once considered science – in some cases, exemplary science. It is hard to imagine how we should expect students to "know better" than these scientists without teaching them why. What has changed? If testability or falsifiablity are benchmarks of modern science, for example, then students should discover, as scientists did historically, how those philosophical principles are important. By tracing the historical context of "wrong" ideas, students learn what makes science "science".

For teaching purposes in the 'school science' tradition (Izquierdo & Adúriz 2003) one possible way to escape from current dominant school chemistry curriculum is incorporating models and modeling in our classrooms (Suckling et al. 1978) but avoiding the use of hybrid models. This must allow students to become able to recognize problems that can be tackled with 'chemical knowledge' (Chamizo 2002), and they must be able to collect, under the teacher's guidance, the relevant knowledge (it means again, evaluation) on their own. Particularly in the recurrent model approach scientific disputes are extremely useful. Pickstone (1995) comments:

> By systematically exploring the mechanism of closure in scientific disputes one may be able to measure the weight given to evidence and the role of accumulating evidence in adjusting the balance between the poles of a dispute.

History is what we can do with what comes to us from the past. But we live and teach in the present. We may like it or not, but it has been stated that we teach the history of chemistry. For that reason, the recurrent historical models, which shows loyalty to the terms of the past and commitment to the problems of the present, appears to be a profitable option.

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