Chapter 11
The Place of the History of Chemistry in the Teaching and Learning of Chemistry

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11.1 Introduction

Numerous isolated appeals for the introduction of more history into the undergraduate chemistry curriculum have been made since the 1950s but with limited success. For example, Conant (1951) used the historical case study approach in teaching science to undergraduate students at Harvard, and his case studies included examples from chemistry, but the historical approach seemed to lapse in the succeeding decades. In 1989 a more coordinated approach was initiated with the formation of the International History, Philosophy and Science Teaching Group (IHPST). At this time Kauffman (1989) wrote a review article on the status of history in the chemistry curriculum in which he summarised the advantages and the disadvantages of using the historical approach. The advantages listed maintained that a study of chemistry in an historical context highlighted chemistry as a human enterprise, as a dynamic process rather than a static product, as depending on interrelationships between historical events, as often multidimensional in its discoveries, as a discipline with strengths and limitations and as depending on intuition as well as logic in its problem-solving activities. Kauffman (1989) also observed that on occasion an historical investigation has assisted the chemist in their current research. The discovery of the noble gas, argon, is quoted as an example (see also Giunta 1998). Lord Rayleigh and Sir William Ramsay published their discovery of argon in 1895 (Rayleigh and Ramsay 1895). Small anomalies found in measurements of the density of nitrogen samples prepared by different methods and the unexplained existence of a residue in Cavendish's (1785) experiments on the passing of electricity through air a century earlier led to the discovery.

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The disadvantages of using the history of chemistry included the fact that there is a fundamental difference in goal and method between chemistry and history. While chemistry, like other sciences, abstracts, idealises, models and simplifies, history attempts to capture the richness of past events in their complexity. In spite of this difference, Kauffman challenges the reader 'to attempt to present to the student a harmonious balance between the two' (Kauffman 1989, p. 86). It is this harmonious balance between chemistry and history that is controversial amongst some professional chemists. If chemistry instruction is designed to enhance the practical skills of the chemist in a number of laboratory settings, for example, one might be able to successfully argue against the inclusion of chemical history in such instruction. If one's purpose, on the other hand, is to educate the student in the broader context of knowledge development and validation, then history is an essential component of chemistry education at the secondary and tertiary level. This would also apply whether the student was studying chemistry as a major discipline or whether the student was a nonmajor in chemistry. Niaz and Rodriguez (2001) argue, however, that history is not something that is added to chemistry. It is already inside chemistry as it were. According to this view, it is difficult to teach chemistry either for skills or understandings without interfacing with its history in some form.

A second disadvantage revolves around the difficulty associated with assessing material that is both historical and chemical. Students, by nature, tend to only take seriously material that is assessed, but the question is how this should be done. Another two disadvantages concern the inappropriate use of a distorted history, often called 'Whig' history, and the likelihood that young students might feel estranged from the study of chemistry when they learn that chemists have not always 'behaved as rational, open-minded investigators who proceed logically, methodically, and unselfishly toward the truth on the basis of controlled experiment' (Kauffman 1989, p. 87). Kauffman (1989) finally discussed briefly four approaches to incorporating history into the chemistry curriculum: the *biographical approach*, the *anecdotal approach*, the *case study approach* and the *classic experiments approach*.

Thirteen years after Kauffman's review, Wandersee and Baudoin-Griffard (2002) contributed a chapter on the history of chemistry in chemical education in a book dedicated to an appraisal of the status of chemical education at the beginning of the twenty-first century. It is interesting to ponder what similarities and differences in perception might be evident in these contributions over this 13-year period. Both articles identify the role of history in teaching about the nature of science (NOS) although by 2002 NOS had developed into a significant research area, whereas in 1989 it was only in the emergence phase. Wandersee and Baudoin-Griffard (2002) give more attention than did Kauffman (1989) to matters associated with student learning such as the comparison of student conceptions with early conceptions in the history of chemistry, the idea of meaningful and mindful (transferable) learning in understanding chemistry and some evidence that supports the notion that exposure to some history of chemistry enhances the learning of chemistry. Wandersee and Baudoin-Griffard (2002), like Kauffman (1989), deal with approaches to incorporating history into the chemistry curriculum, but they focus on Interactive

Historical Vignettes which are ‘a series of lively, carefully crafted, brief (~15 min), interactive’ (Wandersee and Baudoin-Griffard 2002, p. 34) stories tailored to the chemical concepts being studied. These authors lament the fact that only anecdotal evidence is available as of 2002 for the effectiveness of this approach to chemistry teaching and learning.

There has continued to be a burgeoning literature on this topic since 2002 to the extent that a process of categorisation is almost mandatory if one is to make any sense of the research in the field. It has therefore been decided to review the literature using five focus categories: (1) Student Learning, (2) Conceptual Clarity and Development, (3) Chemical Epistemology and the Nature of Science, (4) Pedagogy and Curriculum, and (5) Human Biography. While a large number of articles will deal with more than one of these categories, they will be discussed largely under the category which represents the major focus of the article.

11.2 Student Learning

When one considers the relationship between the history of chemistry and the learning of chemistry, there are two major considerations addressed by the literature. Firstly, there is an interest in the extent to which student conceptions in chemistry mirror those of the early scientists (Piaget and Garcia 1980). Secondly, there is an interest in whether the incorporation of the history of chemistry within chemistry teaching and learning has an impact on chemistry achievement.

The interest in comparing student conceptions with those possessed by scientists or chemists in the past has to do with the capacity of this scholarship to alert teachers to the kinds of thinking patterns of students that might present some resistance to change. Being aware of the history of the concept may provide clues that can assist the teacher in promoting conceptual change. While science educators agree that this might be achievable in some circumstances, they doubt that this can be achieved in all circumstances. It has been noted that ‘Students’ conceptions with limited empirical foundation…. have a completely different ontological status to empirically based ideas that are carefully formulated and sharpened by debate among scientific peers’ (Scheffel et al. 2009, p. 219). Given this proviso these workers examined the significance of student conceptions in the light of current and historical knowledge in the areas of the particulate nature of matter, structure–property relations, ionic bonding, covalent bonding and organic chemistry and macromolecular chemistry. In the case of ionic bonding in crystals, the historical use of particle shape both edgy (Hauy 1743–1822) and ball-like (Hooke 1635–1703) to explain crystal shape was also found to exist in students’ thinking (Griffith and Preston 1992). On the other hand, in the case of the concept of isomerism, it was concluded that ‘The importance of isomerism in the history of science does not correspond to the importance of isomerism in school’ (Scheffel et al. 2009, p. 244), because students’ difficulties with the concept do not correlate with historical ideas (Schmidt 1992). This was also the case for the octet rule in covalent bonding (Taber 1997, 1998). Even though 'the number of concrete studies comparing historical ideas and students' conceptions is fairly low in chemistry education' (Scheffel et al. 2009, p. 220), there are some studies of importance outlined below.

A questionnaire study (Furio-Mas et al. 1987) of students' conception of gases was undertaken with 1,198 pupils aged 12–18 years in Valencia. It was shown that the majority of students tended to adopt an Aristotelian view of a gas in that they believed gases have no weight because they rise rather than fall. In addition, for chemical reactions involving gases as reactants or products, the students thought that mass was not conserved. Younger students adopted a pre-seventeenth-century nonmaterial view of a gas. Fifty-nine science major students enrolled in Chemistry I at a university in Venezuela were asked to respond to a problem which asked them to select which of four particle distribution models represented hydrogen gas at a lower temperature than the one shown in the problem (Niaz 2000a). The most common distribution chosen was that which resembled a 'lattice' structure similar to that understood by scientists before the random distribution model deduced from the kinetic theory of gases in the nineteenth century.

A questionnaire and interview study of 54 year eight Barcelona students' understanding of mixtures, compounds and physical and chemical properties (Sanmarti and Izquierdo 1995) revealed that a significant number assigned a material nature to properties like colour and taste, a view that was held from the sixteenth to the eighteenth century. For example, on observing the dissolution of blue copper sulphate in water, one student said, 'the blue colour of the crystal can leave and pass into the water' (Sanmarti and Izquierdo 1995, p. 361). When blue copper sulphate crystals were heated, the colour change was explained as 'the water evaporates, and when it evaporates it carries this (blue) substance (with it)' (Sanmarti and Izquierdo 1995, p. 361). Sanmarti and Izquierdo (1995) use the term 'substantialisation of properties' to describe this phenomenon.

Van Driel et al. (1998) undertook a study of chemical equilibrium with 120 students aged 15–16 in the Netherlands. Original papers by Williamson (1851–1854), Clausius (1857) and Pfaundler (1867) were used to compare students' written responses to a questionnaire and group oral responses on audiotape with the nineteenth-century historical understanding. The reasoning students used to explain the incompleteness of a chemical reaction resembled the reasoning used by scientists of the nineteenth century particularly when the corpuscular model was used. However, the 'explanations remained incomplete or naïve. The few students capable of giving adequate explanations…implemented statistical notions in their explanations, analogous to Pfaundler's explanation of 1867' (Van Driel et al. 1998, p. 195). Niaz obtained results on a chemical equilibrium study that showed 'that at least some students consider the forward and reverse reactions as a sort of chemical analogue of Newton's third law of motion' (Niaz 1995a, p. 19), that is, action and reaction are equal and opposite.

Cotignola and colleagues (2002) interviewed 31 volunteers from science and engineering courses, 2 years after having studied basic thermodynamics, about the energetic processes associated with material sliding down inclined planes. The students used the word 'heat' predominantly in their explanations and were not able to distinguish it from internal energy. The authors suggest that Clausius followed a similar course when developing the field of thermodynamics in 1850 by focussing on the difference between sensitive heat and latent heat. The students ideas were not as sophisticated of course.

Although the literature comparing historical chemical ideas with student conceptions is not extensive, as previously mentioned, the reader should be aware of the large body of research in the general area of student conceptions. Classic references such as the handbook entry by Wandersee et al. (1994) and those addressing chemistry conceptions[1] are worth reading to put the historical ideas reported here in perspective. Research techniques for diagnosing and interpreting student conceptions can be found in DiSessa (1993), Taber and Garcia-Franco (2010), and Treagust (1988, 1995).

Moving on now to our second point of interest, what can one say about the use of the history of chemistry and chemistry achievement? The literature is not decisive on this matter. Using an experimental and control group of 14-year-olds where the experimental group was given a substantial amount of historical material and taught the same science content as the control group who were not presented with the historical material, Irwin (2000) observed that there was no significant difference between the groups in their understanding of contemporary science content related to atomic theory and periodicity. This was in spite of the fact that the historical approach did portray the nature of science more realistically. However, Lin (1998) did a similar study with 220 eighth graders where the experimental groups studied the historical cases of atmospheric pressure and atoms, molecules and formulae. All experimental and control groups were given four questions requiring conceptual problem solving in the science content. The experimental group did significantly better in conceptual problem solving. Lin et al. (2002) achieved similar results with a group of 74 eighth graders for chemistry conceptual problem-solving ability. The different outcomes to the Irwin study may be due to the nature, not necessarily the validity, of the science content test instruments, and this is worth exploring in further research.

A related matter to that in the previous paragraph is the relationship between history of chemistry and chemistry assessment. Niaz and colleagues (2002) have attempted to show how chemistry might be assessed within the context of historical experiments. In the case of Rutherford's gold foil experiment, for example, a suggested assessment item might be: What might you have deduced if most of the alpha particles were deflected through large angles? Perhaps the relationship between history of chemistry and chemistry achievement might depend on how closely the chemistry content interfaces with the history. This issue requires a more sustained research effort during this decade.

11.3 Conceptual Clarity and Development

History lends itself to giving depth and clarity to concepts, but we know that there is often a compromise between such an approach and that which focuses on the relatively quick generation of an answer to a problem. De Berg (2008a) has discussed

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[1] For example, Andersson (1990), Garnett et al. (1995), Kind (2004), and Taber (2002).

this issue in terms of an approach which emphasises *conceptual depth* over and against *conceptual usefulness* for the chemistry concepts of *energy*, *heat and work*, *element*, *mole* and the *uncertainty principle*. Others (Holme and Murphy 2011) define the difference in terms of *conceptual knowledge* and *algorithmic knowledge*[2]. The *Journal of Chemical Education* publishes many articles which focus on the history of chemistry and its role in giving clarity to concepts. There are at least *eighty-five* such articles published from 2005 to June 2011. Many of these articles show their historical character by having a title commencing with the words 'The Origin of….' The majority of these papers were written by Professor William Jensen who occupies the chair for the History of Chemistry at the University of Cincinnati. Table 11.1 samples Professor Jensen's 'The Origin of….' titles from 2005 to June 2011 with the *Journal of Chemical Education* references included.

Let us take one example from Table 11.1, The Origin of the *s, p, d, f* Orbital Labels, to illustrate how useful these titles can be in enlightening the significance of the symbols we commonly use in chemistry to represent concepts. Jensen (2007a) shows that the symbols originated around 1927 and represented the different line series present in alkali metal spectra. These lines were distinguished using the adjectives *sharp*, *principal*, *diffuse* and *fundamental*. The symbols, *s*, *p*, *d* and *f* were thus taken from the first letter of the names of these four series of lines and applied to the description of electron orbitals because line spectra were attributed to electron transitions between orbitals. It appears that Friedrich Hund was the first to use this nomenclature.

A sampling of 2010, 2011 and some 2012 articles from the *Journal of Chemical Education* which use historical information to bring clarity to the concepts of chemistry, other than 'The Origin Series' in Table 11.1, is given in Table 11.2. Most yearly issues of the journal contain articles which could be classified into at least some of the eight categories in Table 11.2 and serve as a rich resource for chemistry educators. The processes of chemistry which lead to the products of chemistry, some of which are shown in Table 11.2, also have a rich history. For example, an historical approach to the process of distillation 'where the old is redeemed to complement the new' (Lagi and Chase 2009, p. 5) provides a deeper understanding of the separation process in a modern context.

Eric Scerri (2007, 2009) has devoted a large portion of his working life to bringing clarity to the so-called periodic law and the structure of the *periodic table*. Many of the issues such as the difference between thinking of an element as a *basic substance* or a *simple substance* and the concept of *reductionism* are philosophical in nature and will be dealt with in another chapter of the handbook. But Scerri also involves the history of the development of the periodic table to highlight:

1. The renewed importance of Prout's hypothesis particularly if one regards atomic number as an important building block of the elements. Prout's hypothesis proposed that all the elements were compound forms of hydrogen. Accurate atomic weight determinations cast some doubt on the hypothesis in the nineteenth

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[2] See Nakhleh (1993), Nakhleh et al. (1996), Nurrenbem and Pickering (1987), Pickering (1990), and Zoller et al. (1995) for earlier references.

Table 11.1 A sample of 'The Origin of ….' titles written by William Jensen from 2005 to June 2011 and published in the *Journal of Chemical Education*

Title	Reference
The Origin of the Bunsen Burner	(2005a), 82(4), p. 518
The Origin of the 18-Electron Rule	(2005b), 82(1), p. 28
The Origin of the Liebig Condenser	(2006a), 83(1), p. 23
The Origin of the Term 'Allotrope'	(2006b), 83(6), p. 838
The Origin of the s, p, d, f Orbital Labels	(2007a), 84(5), p. 757
The Origin of the Names Malic, Maleic, and Malonic Acid	(2007b), 84(6), p. 924
The Origin of the Polymer concept	(2008a), 85(5), p. 624
The Origin of the Rubber Policeman	(2008b), 85(6), p. 776
The Origin of the Metallic Bond	(2009a), 86(3), p. 278
The Origin of the Circle Symbol for Aromaticity	(2009b), 86(4), p. 423
The Origin of the Ionic-Radius Ratio	(2010d), 87(6), pp. 587–588
The Origin of the Name 'Onion's Fusible Alloy'	(2010e), 87(10), pp. 1050–1051
The Origin of Isotope Symbolism	(2011), 88(1), pp. 22–23

Table 11.2 Historical examples from the *Journal of Chemical Education* (2010–2012) which clarify the concepts of chemistry

Chemistry profile	Examples	Reference
The products of chemistry	Synthetic dyes	Sharma et al. (2011)
	Quinine	Souza and Porto (2012)
The constants of chemistry	Avogadro's constant	Jensen (2010a)
	Atomic Mass, Avogadro's constant, mole	Barariski (2012)
The instrumentation of chemistry	pH meters	Hines and de Levie (2010)
The species of chemistry	Hydrogen ion	Moore et al. (2010)
The laws of chemistry	First law of thermodynamics	Rosenberg (2010)
	Thermodynamics-globalisation and first law	Gislason and Craig (2011)
	Clausius equality and inequality	Nieto et al. (2011)
The symbols of chemistry	R (organic), q, Q (thermodynamics)	Jensen (2010b), (2010c)
The models of chemistry	Bohr-Sommerfeld	Niaz and Cardellini (2011)
	Electronegativity	Jensen (2012)
The phenomena of chemistry	Fluorescence and phosphorescence	Valeur and Berberan-Santos (2011)

century, but a rehabilitation of the hypothesis became possible in the twentieth century based on the concept of atomic number.

2. The significance of the atomic number *triads* in developing a structure for the periodic table. The best form for representing the periodic table is still a matter of dispute. This fact is commonly not recognised by chemists. Scerri (2009) currently favours a form based on the atomic number triad which leads to a very symmetrical table with four groups to the left and four groups to the right of the transition series. The third and fourth transition series should commence with the elements lutetium and lawrencium rather than lanthanum and actinium on

Table 11.3 Some key chemistry concepts discussed in the journal *Science & Education* from an historical perspective including some references

Key chemistry concept	Reference
Gas laws	de Berg (1995), 4(1), pp. 47–64; Woody (2011) online first 6/12/11
Atomic theory	Chalmers (1998), 7(1), pp. 69–84
	Sakkopoulos and Vitoratos (1996), 5(3), pp. 293–303; Viana and Porto (2010), 19(1), pp. 75–90
Work, kinetic and potential energy	de Berg (1997a), 6(5), pp. 511–527
Kinetics	Justi and Gilbert (1999), 8(3), pp. 287–307
Electrolytic dissociation	de Berg (2003), 12(4), pp. 397–419
Acid–base equilibria	Kousathana et al. (2005), 14(2), pp. 173–193
Osmotic pressure	de Berg (2006), 15(5), pp. 495–519
Quantum mechanics	Hadzidaki (2008), 17(1), pp. 49–73
Heat and temperature	de Berg (2008b), 17(1), pp. 75–114
Mole concept	Padilla and Furio-Mas (2008), 17(4), pp. 403–424
Chemical equilibrium	Quilez (2009), 18(9), pp. 1203–1251
Electrochemistry	Eggen et al. (2012), 21(2), pp. 179–189

the basis of the atomic number triad but, this is still controversial. Published periodic tables as late as 2010 (e.g. Atkins and de Paula 2010) have not yet taken Scerri's suggestion seriously enough to change the format.

3. The illusions accompanying the nature of the periodic table. Significance is often given to Mendeleev's successful predictions of unknown elements, but it is rarely mentioned that only about 50 % of his predictions proved correct. The number of outer shell electrons is often used as the basis for the assignment of an element to a vertical group of the table. However, there are exceptions to this rule. Helium has the same number of outer shell electrons as the alkaline earth metals but is normally placed with the noble gases because of its inert characteristics. Nickel, palladium and platinum are in the same vertical group but have a different outer shell electron configuration.
4. The fact that the periodic system was discovered essentially independently by six scientists. Of these six, Mendeleev has been given the greatest credit for various reasons even though it could be argued that the German chemist Lothar Meyer was the first to produce, in 1864, a mature periodic system which was even more accurate than that produced by Mendeleev in 1869.

The journal, *Science & Education*, is dedicated to conceptual clarity through the lens of history and philosophy. A summary of some of the key concepts in chemistry which have been addressed in this journal is given in Table 11.3.

Some key chemistry concepts such as work and energy, fundamental to an understanding of thermodynamics, contain mathematical formulations of rich historical significance. For example, de Berg indicates that:

> the mathematical relationship, $mgh = \frac{1}{2} mv^2$, for free fall, could have been known from the time of Galileo and Newton….but the physical significance of the equation was not recognized till the early 19th century. That is, while the mathematics was in place by the 17th

> century, the fact that ½ mv^2 and mgh were measures of fundamental quantities was not known for 200 years. The physical notions of mechanical action (work) and force of a body in motion (kinetic energy) had separate historical developments…(but) their relationship (was finally) recognized in the 19th century and ultimately this paved the way for the development of the general concept of energy. (de Berg 1997a, p. 515)

The historical approach to the mathematical equations associated with chemistry concepts adds physical and conceptual significance to the equations beyond their algorithmic value.

11.4 Chemical Epistemology and the Nature of Science

How a chemist forms and validates chemical knowledge is central to an understanding of the nature of chemistry or chemical literacy. There is some debate about what is meant by the terms 'chemical literacy' and 'nature of chemistry' or the more general expressions 'scientific literacy' and 'nature of science'. For example, McComas et al. (1998) isolated what they considered to be 14 consensus statements regarding the nature of science (NOS), Abd-El-Khalick (1998, 2005) suggested seven statements, and Niaz (2001b) used eight statements. Unanimity of opinion is hard to reach when it comes to defining NOS. A useful summary of the issues is given by Lederman (2006).

Some authors claim that a study of the history of chemistry enhances an understanding of the NOS. For example, Irwin (2000) exposed an experimental group of 14-year-olds to historical episodes associated with the concept of the atom and the periodicity of the elements and found gains, compared to a control group, in understanding aspects of the nature of science such as the usefulness of theories even when there may be some uncertainty about the validity of a theory. Lin and Chen (2002) observed that pre-service chemistry teachers' understanding about the NOS was promoted by a study of the history of chemistry. In particular, the experimental group had a better understanding of the nature of creativity, the theory-based nature of scientific observations and the functions of theories. However, Abd-El-Khalick and Lederman (2000) found that coursework in the history of science (included atomic theory) does not necessarily enhance students' and pre-service science teachers' views of the NOS unless specific aspects of the NOS are also addressed.

Rasmussen (2007) has suggested that exposure to the history of chemistry in general chemistry classes can help students identify pseudoscientific attitudes in advertising. For example, the suggestion is made that introducing students not only to our current understanding of matter but to understandings held over centuries, some of which were erroneous, helps students address such assignment tasks as:

> A favourite claim of many advertisers is that their product is all-natural and thus contains no chemicals. In terms of our class lectures, explain why this is or is not a valid claim. (Rasmussen 2007, p. 951)

Giunta (2001) also focuses on errors that have surfaced in the development of chemical knowledge but from the point of view of the value that erroneous theories, such as the phlogiston theory, have played in furthering our knowledge of chemistry. Dalton's atomic theory, while containing some misplaced ideas according to our current knowledge, was an important stepping stone in leading to the concept of atomic weight. On the other hand, Giunta (2001) shows how a correct hypothesis such as Avogadro's hypothesis was rejected by a number of chemists at the time it was proposed for understandable reasons. The diatomic molecule proposal did not prove compelling enough to chemists to warrant acceptance of Avogadro's hypothesis. Giunta observes that 'the right hypothesis languished or at least struggled for decades' (Giunta 2001, p. 625). This illustrates how difficult it is for the scientific community to transition from one scientific model to another.

The notion of errors in the production of knowledge leads naturally into the significance of historical controversies in the progress of scientific knowledge.

De Berg (2003) has outlined the issues which were involved in the controversy between the Arrhenius School and the Armstrong School at the close of the nineteenth century in relation to the interpretation of what happens at the molecular level when a salt is dissolved in water, the so-called electrolytic dissociation controversy. One of the interesting factors associated with this controversy is the orientation taken to anomalous data. In the data produced by Raoult (1882a, b, 1884), it was clear that the molecular lowering factor associated with freezing point depression for sodium chloride (35.1) was close to double that for ethanol (17.3) and that for calcium chloride (49.9) close to three times that for ethanol. This data was consistent with the electrolytic dissociation hypothesis. The molecular lowering data for magnesium sulphate (19.2) and copper sulphate (18.0) proved anomalous however. One would have expected values close to those for sodium chloride (35.1) if the electrolytic dissociation hypothesis was applicable.

Fortunately these anomalies were held in suspension until they were explained in terms of the production of ion pairs due to the strong charges associated with both cation and anion. Chemists have learnt how futile it is to dispense with theoretical models too early as anomalies often lead to new knowledge provided one is happy to hold them in tension for a period of time. Sometimes anomalies will lead to a new paradigm such as a view of the solid state which includes aperiodic quasicrystals which have a non-repeating pattern at the microscopic level. Until Nobel Laureate Dan Shechtman (Nobel Prize in Chemistry 2011) discovered these in 1982, it was thought that one could not have a crystal without the existence of a repeating pattern of atoms. Controversy highlights how important it is for students to see chemistry as a human enterprise (Niaz 2009). It also indicates the dynamic nature of chemical knowledge, a point emphasised by modern philosophers of science (Machamer et al. 2000).

Chemical history can also be helpful in showing how the knowledge of a particular chemical compound has changed and progressed over time. De Berg (2008c, 2010) has illustrated the strength of this approach using the compound, tin oxide. One can discuss the chemistry of tin oxide over the three periods of chemical revolution described by Jensen (1998a, b, c): the period associated with the determination of chemical composition (1770–1790) at the macroscopic level, at the microscopic level (1855–1875) and finally at the electronic level (1904–1924). The nature of the chemistry associated with the development of an understanding of tin(IV) oxide in particular is shown by de Berg (2010) to involve, progressively from about 1800 to the present, descriptive chemistry, compositional studies, structural studies and advanced materials research. This kind of study gives a deep perspective to current research and might be one way of attracting more practising chemists to take an interest in the history of their subject.

When it comes to the development of a new chemical compound or a commercially viable form of a known compound, one must not forget the role that developments in the broader community such as that in economics, politics, technology and industry play in such developments. Coffey (2008, Chaps. 4 and 6) gives an insightful historical background to the commercial manufacture of ammonia by Haber and Bosch in the early twentieth century. What made the discovery so crucial was the perceived impending famine about to strike in Britain and Europe and its relief through the use of ammonia for the fertiliser industry. Ammonia was also earmarked for its role in the explosives industry, particularly at the onset of war in Europe. Chemical compounds can save lives; but they can unfortunately also take lives.

What is interesting about the historical approach to a discipline is how history pinpoints changes in the nature of discipline knowledge itself. In chemistry, for example, this is particularly noticeable in the way chemists described chemical reactions. In the case of combustion reactions, Joseph Priestley applied the phlogiston model for understanding the chemical change. The heating of a metal in air resulted in the release of phlogiston (the inflammability principle) from the metal to produce the calx. The concept of ‘principle’ was important in chemistry up until the end of the eighteenth century, although it did retain some use into the nineteenth century, so that chemists talked about the inflammability principle, the acid principle, the alkaline principle, the electrical principle, the magnetic principle and so on. Toward the end of the eighteenth century, however, Antoine Lavoisier claimed it was better to think of combustion of a metal in air as a chemical combination of the metal with the oxygen in the air. Chemical reactions were increasingly described in terms of atoms, ions and molecules rather than in terms of ‘principles’. The Priestley-Lavoisier debate as a debate in terms of the nature of chemical knowledge is discussed by de Berg (2011).

11.5 Pedagogy and Curriculum

One way of describing chemistry curricula is to examine the textbooks used by teachers and students. It is not surprising then that chemistry textbooks have been targeted as a source of research into chemistry curricula. In particular, the focus here will be on the way chemistry history is portrayed and used in chemistry textbooks. Van Berkel, De Vos, Verdonk and Pilot regard textbook chemistry as portraying what Kuhn (1970) would have called ‘normal science’ in that 'normal chemistry education is isolated from common sense, everyday life and society, history and philosophy of science, technology, school physics and from chemical research' (Van Berkel et al. 2000, p. 123). The general tenor of the research on chemistry textbooks has been rather critical of the portrayal and use of history when it has appeared, and more detail will be given in another chapter of the handbook. For the purposes of this section, some of the studies are summarised in Table 11.4 below.

Three of the references in Table 11.4 show how chemistry was portrayed in early textbooks, and it was often the case that the textbook was the main source of chemical information. France was the centre of the 'new chemistry' or the 'chemical revolution' with Lavoisier's influence predominating, and it is interesting to observe how this new chemistry was incorporated into textbooks of the era. Early textbooks of the twentieth century such as Partington's (1953) *Textbook of Inorganic Chemistry* contain significant amounts of historical material compared with later twentieth-century textbooks.

Researchers tend to be critical of more recent textbooks of chemistry either for the lack of historical material or for the way the historical material is presented. For example, Niaz (2000b) observed that, in discussing the oil drop experiment, the authors of chemistry textbooks did not give adequate treatment to the Millikan-Ehrenfest controversy. The oversimplification of the description of the experiment gives students the impression that the oil drop experiment yielded results with ease and without controversy. Holton (1978) has described how difficult this experiment was to perform and interpret. There are difficulties even when using modern apparatus (Klassen 2009). The question arises as to whether textbook authors can be expected to deal with historical material to the satisfaction of the historian or the chemist interested in history as well as presenting current trends in the subject. One option is to look at presenting the historical material in other ways.

Table 11.4 Some studies relating to the use of the history of chemistry in chemistry textbooks

Targeted chemistry concept	Reference
Covalent bonding	Niaz (2001a)
Models of the atom	Justi and Gilbert (2000)
Gases	de Berg (1989)
Electrochemistry	Boulabiar et al. (2004)
Periodic table	Brito et al. (2005)
Oil drop experiment	Niaz (2000b), Niaz and Rodriguez (2005)
Chemical revolution—late eighteenth century/early nineteenth century	Bertomeu-Sanchez and Garcia-Belmar (2006)
Chemical theories—late eighteenth century and early nineteenth century	Seligardi (2006)
Atomic structure	Niaz and Rodriguez (2002)
Aims and scope of chemistry in seventeenth-century France	Clericuzio (2006)
Amount of substance and mole	Furio-Mas et al. (2000)

Hutchinson (2000) has taken the concepts typically taught in general chemistry in university courses and expressed them in terms of nine case studies. For example, Case Study 3 on 'Periodicity and Valence' 'uses the experimental facts which were actually used to develop these concepts, and so introduces an historical perspective to their learning' (Hutchinson 2000, p. 4). This approach to experimental data is used in all the case studies. The purpose of the case studies is to teach chemistry not history, but historical experiments are used to show students how concepts are developed and models are built and how to distinguish between the data and its interpretation. In relation to models and theories, Hutchinson counsels that:

> It is very important to understand that scientific models and theories are almost never *proven*, unlike mathematical theorems. Rather, they are logically developed and deduced to provide simple explanations of observed phenomenon. As such, you will discover many times in these Case Studies when a conclusion is not logically required by an observation and a line of reasoning. Instead, we may arrive at a model which is the simplest explanation of a set of observations, even if it is not the only one. (Hutchinson 1997, Preface)

This curriculum is used for general chemistry at Rice University.

Niaz (2008) has written a book entitled, *Teaching General Chemistry: A History and Philosophy of Science Approach*, which can be used as a companion text to the student textbook by teachers. The emphasis is on conceptual problem solving in contradistinction to algorithmic problem solving and is based on the premise that the difficulties students face in conceptualising problems are similar to the difficulties scientists of an earlier period in the history of chemistry faced. The general chemistry concepts featured in the text include the mole, stoichiometry, atomic structure, gases, energy and temperature and chemical equilibrium. The text draws heavily upon research data related to student understanding of chemistry concepts. The approach is best illustrated by an example. In the chapter on gases, Niaz defines his approach as follows:

> The main objective of this section is to construct models based on strategies students use to solve the gas problems and to show that these models form sequences of progressive transitions similar to what Lakatos (1970) in the history of science refers to as progressive 'problemshifts'. Guideline 1 (defined in his chapter 3) suggests a rational reconstruction of students' understanding of gases based on progressive transitions from the 'algorithmic mode' (work of Boyle and others in the 17th century) to 'conceptual understanding' (work of Maxwell and Boltzmann in the 19th century). Results reported here are from Niaz (1995b). (Niaz 2008, p. 67)

The results of a study of the responses of sixty (N = 60) freshmen chemistry students to two items testing an understanding of gases are then discussed. The two items are shown below.

Item A

A certain amount of gas occupies a volume (V_1) at a pressure of 0.60 atm. If the temperature is maintained constant and the pressure is decreased to 0.20 atm, the new volume (V_2) of the gas would be:

$$(a)\,V_2 = V_1/6 \quad (b)\,V_2 = 0.33\,V_1 \quad (c)\,V_2 = V_1/3 \quad (d)\,V_2 = 3\,V_1$$

> *Item B*
> An ideal gas at a pressure of 650 mmHg occupied a bulb of unknown volume. A certain amount of the gas was withdrawn and found to occupy 1.52 mL at 1 atm pressure. The pressure of the gas remaining in the bulb was 600 mmHg. Assuming that all measurements were made at the same temperature, calculate the volume of the bulb (Niaz 2008, p. 68).

Niaz considers that *Item A* involves algorithmic problem solving and *Item B* conceptual problem solving. It was observed that 87 % of the students solved *Item A* correctly, whereas only 7 % of the students solved *Item B* correctly. The remaining students gained only partial credit for their answers. Niaz proposes that:

> Based on (the) strategies used in solving *Items A* and *B* it is plausible to suggest that students go through the following process of progressive transitions…
>
> Model 1: Strategies used to solve *Item A* correctly, that is, ability to manipulate the three variables of the Boyle's Law equation ($P_1V_1 = P_2V_2$) to calculate the fourth (N = 52).
>
> Model 2: Strategies used to correctly identify the final volume in *Item B*, that is, partial conceptualization of the property of a gas when it is withdrawn from a vessel (N = 16).
>
> Model 3: Strategies used to correctly identify and conceptualize two properties of a gas (final volume and pressure in *Item B*), when it is withdrawn from a vessel (N = 13).
>
> Model 4: Strategies used to correctly identify and conceptualize all the variables of a gas (*Item B*) when it is withdrawn from a vessel (N = 4). (Niaz 2008, p. 68)

In Model 4, it could also be considered that a strategy involving the additive property of 'amount of gas' where 'amount of gas' was understood as either mass, moles or particle number is important. The particle model of a gas, endemic to kinetic theory, leads to this conclusion.

Another strategy for incorporating the history of chemistry in chemistry curricula is the development and use of what de Berg (2004) calls a pedagogical history. A pedagogical history combines a knowledge of chemistry, history of chemistry, student learning and philosophy of science to develop an instructional storyline which requests students to engage with the text. Where possible, students are asked to interact with historical experimental data and to make decisions about how well the data fits the model. For example, in the case of the electrolytic dissociation model, students are presented with a table of molecular lowering factors from historical sources and asked two questions as follows:

Question 1
Which data do you think fits the model and which data, if any, doesn't fit the model?

Question 2
Now assess, in your view, how strongly the data in the table supports an ionic dissociation model.

The table of data contained some anomalous results although it is true that the majority of the data supported the model, but students had to decide which pieces of information were anomalous and to wrestle with the concept of the weight of evidence. Student reactions to some pedagogical histories have been published, (de Berg 1997b) and the issues involved in selecting the historical data to include in a pedagogical history are presented in a publication dealing with the case of the concepts of heat and temperature (de Berg 2008b).

11.6 Human Biography

Arguments for including history of chemistry in chemistry teaching and learning have always included the thought that history humanises chemistry. To humanise chemistry, however, we need to know something about the life story of the chemists involved, that is, their human biography. It has been maintained that:

> There is particular value in viewing the historical aspect of chemistry through a study of the lives of important chemists because the development of chemical concepts can then be seen in the context of the experiences of fellow human beings……In essence, the students learn that the development of science is a function of the people who develop it and the environment in which they live. (Carroll and Seeman 2001, p. 1618)

Carroll and Seeman (2001) describe how they incorporated scientific autobiography into a senior undergraduate course in advanced organic chemistry. Students studied the autobiography of the organic chemist, Ernest L. Eliel, and five of his key articles published over a period of 40 years. Collaborative group work and oral presentations were a feature of the methodology used. One student commented that 'Learning about Eliel's life caused me to be more interested in understanding the chemistry in the journal articles. We were able to see how the logical progression of his scientific research coincided with his life' (Carroll and Seeman 2001, p. 1620).

While Carroll and Seeman (2001) combined a study of a chemist's life story with a study of five of his most important chemistry publications at the senior undergraduate level, they suggested that a softer approach is probably better at the introductory level. The use of interesting 'incidental information' was recommended which 'can help make a human connection with the abstract concepts and does not require much class time' (Carroll and Seeman 2001, p. 1619). In Table 11.5 some examples of 'incidental information' for a range of chemists has been assembled with some important biographical references.

Table 11.5 Incidental information for a range of chemists along with important biographical references

Chemist	Incidental information	Biographical reference
Robert Boyle (1627–1691)	Very rich; wore a wig; never married; had an interest in alchemy and the turning of base metals into gold; had poor eyesight; intensely religious and supported the translation of the bible into different languages	Hunter (2009)
Joseph Priestley (1733–1804)	Discovered dephlogisticated air (oxygen); used his wife's kitchen as a laboratory; had a speech impediment but taught oratory; his house was burnt down because of his sympathies with the American and French Revolutions; was a dissenting minister; encouraged by Benjamin Franklin to take up science as a serious study	Matthews (2009) Schofield (1997, 2004)

(continued)

Table 11.5 (continued)

Chemist	Incidental information	Biographical reference
Michael Faraday (1791–1867)	Started work as a book binder; learnt chemistry from Humphry Davy; became famous for his chemistry demonstrations at the Royal Institution in London; gave us the names ‘anode’ and ‘cathode’ in electrochemistry; 96,500 coulombs per mole named after him	Williams (1965)
Dmitri Mendeleev (1834–1907)	Had 13 siblings; born in Siberia; his mother encouraged him to take up science; dynamic educator who attracted students from all faculties of the university to his lectures; fond of art; organised special classes in chemistry for women although he believed women to be inferior to men intellectually; famous for the periodic table; always pictured with a cigarette in his hand; believed in only getting his hair cut once a year	Byers and Bourgoin (1998) Scerri (2007)
Svante Arrhenius (1859–1927)	Swedish with stocky build, ruddy complexion, blonde hair and blue eyes; loved scientific controversy; his Ph.D. regarded as not of sufficient standard for an academic position but granted the Nobel Prize in chemistry in 1903 for his electrolytic dissociation theory; only married for a short time as his wife objected to his drinking and smoking; one of the first chemists to talk about the greenhouse effect	Crawford (1996)
Marie Curie (1867–1934)	Discoverer of the radioactive substance, radium; married Pierre; twice a Nobel Prize winner; 1903 shared Nobel Prize in Physics with husband Pierre and Henri Becquerel for work on radioactivity; won 1911 Nobel Prize in chemistry for discovering radium and polonium; had to work against gender bias; disapproved of fashion in dress; reared in poverty	Goldsmith (2005)
Martha Whiteley (1866–1956)	In a male-dominated field, she played a critical role on the academic staff of Imperial College London and secured admission of women chemists to the Chemical Society. She edited the multivolume Thorpe’s Dictionary of Applied Chemistry	Nicholson and Nicholson (2012)
Ernest Rutherford (1871–1937)	Country boy from the South Island of New Zealand; known for the development of simple but elegant experiments on the atomic nucleus; although not religious would sing ‘Onward Christian Soldiers’ with volume when an experimental breakthrough occurred; his ashes are buried in Westminster Abbey near that of Sir Isaac Newton	Campbell (1999) Reeves (2008) Wilson (1983)
Gilbert Lewis (1875–1946)	Famous for proposing the electron pair covalent bond and the octet rule; homeschooled entirely through elementary school; could read at age 3; learnt five languages; reserved in nature	Coffey (2008)

Table 11.6 A list of chemists discussed in the *Journal of Chemical Education* from the year 2000 to June 2011 along with the author reference

Chemist	Reference
Boerhaave (1668–1738)	Diemente (2000), 77(1), p. 42
Rutherford (1871–1937)	Sturm (2000), 77(10), p. 1278
Faraday (1791–1867)	Clark (2001), 78(4), p. 449
Pauling (1901–1994)	Davenport (2002), 79(8), p. 946
Mendeleev (1834–1907)	Marshall (2003), 80(8), p. 879
Priestley (1733–1804)	Williams (2003), 80(10), p. 1129
Bohr (1885–1962)	Peterson (2004). 81(1), p. 33
Porter (1920–2002)	Kovac (2004), 81(4), p. 489
Lavoisier (1743–1794)	Jensen (2004), 81(5), p. 629
Starkey (1628–1665)	Schwartz (2004), 81(7), p. 953
Boltzmann (1844–1906)	David (2006), 83(11), p. 1695
Haber (1868–1934)	Harris (2006), 83(11), p. 1605
Mendeleev (1834–1907)	Benfey (2007), 84(8), p. 1279
Boyle (1627–1691)	Williams (2009), 86(2), p. 148

Table 11.7 A sample of short biographies written by George Kauffman and published in the *Chemical Educator*

Chemist	Reference
Moses Gomberg (1866–1947)	(2008a), 13(1), pp. 28–33
Arthur Kornberg (1918–2007)	(2008a), 13(1), pp. 34–41 (with J. Adloff)
Antoine Henri Becquerel (1852–1908)	(2008b), 13(2), pp. 102–110
Frederic Joliot (1900–1958)	(2008c), 13(3), pp. 161–169
Fred Allison (1882–1974)	(2008b), 13(6), pp. 358–364 (with J. Adloff)
Gerald Schwarzenbach (1904–1978)	(2008d), 13(6), pp. 365–373
Dwaine O. Cowan (1935–2006)	(2009), 14(3), pp. 118–129
Osamu Shimomura (1928–)	(2009), 14(2), pp. 70–78 (with J. Adloff)
Alfred Maddock (1917–2009)	(2010a), 15, pp. 237–242 (with J. Adloff)
Marie and Pierre Curie (1859–1906)	(2010b), 15, pp. 344–352 (with J. Adloff)
Marie Curie (1867–1934)	(2011a), 16, pp. 29–40 (with J. Adloff)
Robert Bunsen (1811–1899)	(2011b), 16, pp. 119–128 (with J. Adloff)
John Bennett Fenn (1917–2010)	(2011c), 16, pp. 143–148 (with J. Adloff)
William Nunn Lipscomb (1919–2011)	(2011d), 16, pp. 195–201 (with J. Adloff)

From time to time, the *Journal of Chemical Education* will publish some useful and interesting biographical material on an important chemist. In Table 11.6 is recorded a list of chemists discussed in this journal from the year 2000 to June 2011. Some of the references report on an important book review.

George Kauffman writes short biographies of chemists for the *Chemical Educator* and a selection from 2008 to 2011 is shown in Table 11.7.

11.7 Conclusion

Much progress has been made in humanising the teaching and learning of chemistry through history since the first IHPST conference in 1989. However, measuring the impact of the history of chemistry on the teaching and learning of chemistry is still an area that needs further investigation. There appears to be no clear answer as far as academic achievement is concerned. Anecdotal evidence suggests that attitudes to and interest in chemistry can be improved by the historical approach, but well-planned research studies need to explore this possible relationship in more detail. We have noted some interesting ways that the history of chemistry has been used in chemistry curricula but if the impact is to be strengthened and grown, one will need to consolidate the history with the content of chemistry or, one might argue, to consolidate the current content with the history. I think that this will be the only way that teachers of chemistry will become convinced of the value of including an historical perspective. Clough (2009) has endeavoured to integrate history with content using thirty case studies, six of which are in chemistry. De Berg (2008c, 2010) has shown how history can embellish an understanding of a chemical compound from its antiquity to current research. Carroll and Seeman (2001) have shown how publications of a chemist from the embryonic stage of a career to the mature stage, that is, according to a chemist's historical journey, can be used to inform current chemistry content. These efforts have at least begun the journey of not only humanising but informing current content.

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