DOCUMENT RESUME

ED 434 811		SE 062 822
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TITLE	Philosophy of Chemistry: An Emerging Field with Implications for Chemistry Education.	
PUB DATE	1999-09-00	
NOTE	10p.; Paper presented at the History, Philosophy and Science Teaching Conference (5th, Pavia, Italy, September, 1999).	
PUB TYPE	Opinion Papers (120) -- Speeches/Meeting Papers (150)	
EDRS PRICE	MF01/PC01 Plus Postage.	
DESCRIPTORS	*Chemistry; Educational Change; Foreign Countries; Higher Education; *Philosophy; Science Curriculum; *Science Education; *Science Education History; *Science History; Scientific Principles; Secondary Education; Teaching Methods	

ABSTRACT

Traditional applications of history and philosophy of science in chemistry education have concentrated on the teaching and learning of "history of chemistry". This paper considers the recent emergence of "philosophy of chemistry" as a distinct field and explores the implications of philosophy of chemistry for chemistry education in the context of teaching and learning chemical models. This paper calls for preventing the mutually exclusive development of chemistry education and philosophy of chemistry, and argues that research in chemistry education should strive to learn from the mistakes that resulted when early developments in science education were made separate from advances in philosophy of science. Contains 54 references. (Author/WRM)

PHILOSOPHY OF CHEMISTRY: AN EMERGING FIELD WITH IMPLICATIONS FOR CHEMISTRY EDUCATION

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ABSTRACT

Traditional applications of history and philosophy of science in chemistry education have concentrated on the teaching and learning of 'history of chemistry'. In this paper, I report on the recent emergence of 'philosophy of chemistry' as a distinct field and explore the implications of philosophy of chemistry for chemistry education in the context of teaching and learning of chemical models. The present work presents an early signal for educational research by calling for the prevention of a mutually exclusive development of chemistry education and philosophy of chemistry. Research in chemistry education should strive to learn from the mistakes that resulted when the early developments in science education were made mainly separate from advances in philosophy of science.

HISTORY AND PHILOSOPHY OF CHEMISTRY AND CHEMISTRY EDUCATION

Overlap of chemistry education research with revived efforts in the application of history and philosophy of science (HPS) to science education has been minimal (Kauffman, 1989). Brush (1978) has argued that the anti-historical nature of chemistry education is a reflection of chemists' marginal interest in the historical dimensions of their science. This claim confuses the status of chemistry education research with the status of the historical and philosophical dimensions of chemistry itself. Many chemists have contributed to historical analyses of their discipline (Kauffman & Szmant, 1984; Partington, 1957). The so-called 'chemist-historians' including Kopp, Thomson, Berthelot, Ostwald and Ihde have maintained a long tradition of interest in history of chemistry (Russell, 1985). Furthermore in the United States, for instance, suggestions for the inclusion of history of chemistry in chemistry teaching can be traced back to the 1930s, to chemists (Jaffe, 1938; Oppe, 1936; Sammis, 1932).

The central argument for the inclusion of history of chemistry in chemistry instruction has been grounded in the need to motivate students' learning (Bent, 1977; Brush, 1978; Heeren, 1990). Often however, history of chemistry, written by chemists from the perspective of the present status of their science consists of 'Whiggish history' (Butterfield, 1949): history written from the perspective of contemporary values and criteria. Furthermore, history of chemistry is typically based on the members' account of chemistry (Pumfrey, 1989). A member's account extracts from the past what is useful for the present, such as good examples of experimental discovery. What needs to be promoted instead, is a stranger's account of history of chemistry: an analysis of historical events without taking for granted what seems self evident to us today (Ellis, 1989).

The implication of the member's versus stranger's account issue is that what seems to be self-evident of historical assumptions are not to be taken for granted but are meant to be investigated with utmost care (Shortland & Warwick, 1989). Chemists' current criteria may make oxygen natural and phlogiston fictional but historical explanations demand more than such classifications. Oxygen was not taken for granted in the eighteenth century. Historians need to examine, then, what is taken for granted to see why it is taken for granted. Since

Paper to be presented at the Fifth History, Philosophy and Science Teaching Conference, Pavia, Italy, September 1999.

eighteenth century chemists could not know the outcome of the debate around oxygen, the historian needs to examine the social and personal factors to explain the actions taken by chemists. Of relevance to chemistry education is that students come to the chemistry classroom not as members but as strangers. They are unlikely to share all of the assumptions that are necessary to see a certain experiment as educators or chemists would see them.

Although history of chemistry has captured the interest of chemists and found its way into the curriculum (Akeroyd, 1984; Ellis, 1989; Herron, 1977; Kauffman, 1989), philosophical dimensions of chemistry have not received as much attention (Scerri, 1997; van Brakel, 1994). Some of the central questions in philosophy of science, such as the distinctive features of science from other endeavors, have been traditionally addressed in terms of what is considered to be the paradigm science: physics. Although the emphasis on the logical analysis of scientific theories have been challenged by philosophers such as Popper and Kuhn, the legacy of logical positivism as well as physics' dominance in philosophical analyses persist.

Reductionism has been regarded as a major factor that inhibited the development of chemical epistemology (Del Re & Liegener, 1987; Primas, 1983; van Brakel & Vermeeren, 1981). From the logical positivist perspective, chemistry was viewed as being reducible to quantum mechanics where lies the philosophical problems of science (Pauling, 1985). Reduction of one science to another was argued on the basis of correspondence and derivation of laws across these sciences (Nagel, 1961; Nye, 1993). The argument that chemistry is a reduced science has not gone uncritisized by chemists nor philosophers of science (Scerri, 1994a; van Brakel, 1994). Hoffmann & Torrence (1993) have questioned the credibility of reductionist claims:

> "The French rationalist tradition, and the systematization of astronomy and physics before the other sciences, have left science with a reductionist philosophy at its core. There is supposed to exist a logical hierarchy of the sciences, and understanding is to be defined solely in vertical terms as reduction to the more basic science. The more mathematical, the better. So biological phenomena are to be explained by chemistry, chemistry by physics, and so on. The logic of reductionist philosophy fits the discovery metaphor- one digs deeper and discovers the truth. But reductionism is only one face of understanding. We have been made not only to disassemble, disconnect, and analyze but also to build. There is no more stringent test of passive understanding than active creation. Perhaps "test" is not the word here, for building or creation differ inherently from reductionist analysis. I want to claim a greater role in science for the forward, constructivist mode." (Hoffmann & Torrence, 1993, p. 67-78)

The assumption that chemistry is a reduced science prevails (Zuckermann, 1986). It is important to note, however, that philosophers of science have not been able to demonstrate that laws can be axiomatized in the first place let alone that they can be derived across disciplines (Scerri, 1994a). It is further questionable whether or not predictive and explanatory power of laws, conventionally taken to be among the decisive criteria for determining a paradigmatic science, carry the same importance and emphasis, to the same extent in different sciences. Whereas the history of physics includes numerous dramatic predictions such as the bending of starlight in gravitational fields and the existence of the planet Neptune, chemistry is not known for its predictive successes.

Scerri (1991) argues that chemistry differs from physics generally not in terms of issues of prediction but in terms of classification. Whereas predictions in physics are based on mathematical models, chemical models rely more on the qualitative aspects of matter. Chemistry has traditionally been concerned with qualities such as color, taste and smell. Although both physics and chemistry involve quantitative and dynamic concepts, such concepts are often accompanied by qualitative and classificatory concepts in chemistry, as is also typical in biology. Furthermore, class concepts are used in chemistry as a means of representation. Some examples are 'acid', 'salt', and 'element'. These class concepts help chemists in the investigation and classification of new substances, just as biology is concerned with classification of organisms. Unlike in chemistry and biology, in physics the tendency is

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towards mathematisation, not classification of physical phenomena. Such differences that set apart chemistry from physics as a distinct domain of scientific inquiry have been overlooked within the reductionist framework.

Although chemistry has typically been presented as a branch of physics not capturing sufficient attention within philosophy of science, it is important to note that chemistry demands a particular link to philosophy. In posing questions of reduction of one science, such as biology to another, namely physics, one cannot ignore the question of whether or not chemistry can be reduced to physics. If reduction of chemistry to physics fails, then reduction of biology to physics is even more unlikely since chemistry is often been regarded as an intermediary science between physics and biology (Kauffman & Szmant, 1984).

Recent developments in philosophy of science have concentrated on naturalistic analyses of the sciences in which one examines more closely what the practitioners themselves might mean by issues such as reductionism (Kornblith, 1985). For chemists and physicists, the attempt to reduce chemistry to physics consists of quantum chemistry which has been developing since the birth of quantum mechanics. Chemists would argue that although some chemical laws relate to physical laws, certain aspects of chemical principles do not necessarily reduce to physical principles. For instance, does the periodic law count as a scientific law in the same sense as Newton's laws of motion? Certainly the arrangement of elements in the periodic table provided some of the most dramatic predictions in the history of science: predictions by Mendeleev of the elements, gallium, germanium and scandium. Such predictions, however, could not have been made at the level of quantum chemistry (Scerri, 1994b).

PHILOSOPHY OF CHEMISTRY: AN EMERGING FIELD

There is increasing interest in the examination of chemistry as a distinct branch of science. An emergent group of philosophers of science (Green, 1993; Hendry, 1993; Plesch, 1993; Scerri, 1996; van Brakel, 1994) have contributed to the formulation of the new field, philosophy of chemistry. The First International Conference on Philosophy of Chemistry was held in 1994. The 1997 annual meeting of the American Chemical Society has devoted a session to issues surrounding the interplay of philosophy and chemistry. The first issue of a new journal, *Foundations of Chemistry*, dedicated to philosophy of chemistry, has recently been published in February 1999.

Given that philosophy of chemistry is an emerging field of study, it is not surprising that science education literature has barely addressed the applications of this field in chemistry education (e.g. Ellis, 1989; Erduran, 1997; 1995, 1997; Novak, 1984). There is much work to be done in aligning chemistry education with the new perspectives on chemical epistemology. Models and modeling provides a crucial and relevant context through which epistemological aspects of chemistry can be promoted in the classroom.

MODELS AND MODELING IN PHILOSOPHY OF CHEMISTRY

The role of models in chemistry has been underestimated since the formulation of quantum theory at the turn of the century. There has been a move away from qualitative or descriptive chemistry (which relies on development and revision of chemical models) towards quantum chemistry (which is based on the quantum mechanical theory). Increasingly, chemistry has emerged as a reduced science where chemical models can be explained away by physical theories:

> "In the future, we expect to find an increasing number of situations in which theory will be preferred source of information for aspects of complex chemical systems." (Wasserman & Schaefer, 1986, p. 829)

Atomic and molecular orbitals, formulated through quantum chemistry, have been used to explain chemical structure, bonding and reactivity (Luder, McGuire & Zuffanti, 1943; Nagel, 1961).

Only recently has an opposition to quantum chemistry (van Brakel & Vermeeren, 1981; Zuckermann, 1986) begun to take shape with a call for a renaissance of qualitative chemistry. Underlying the emergent opposition is the argument that quantum chemistry has no new predictive power for chemical reactivity of elements that descriptive chemistry does not already provide (Scerri, 1994b). Rearrangement of the Periodic Table of elements away from the original proposed by Mendeleev and others, for instance, towards one based on electronic configurations first suggested by Niels Bohr yield no new predictions about chemical or physical behavior of elements. Furthermore, no simple relation exists between the electron configuration of the atom and the chemistry of the element under consideration. In summary, there is no evidence to suggest that new physical and chemical behavior of elements can be explained or predicted by quantum theory.

What the preceding discussion demonstrates is that although models have historically been central in the growth of chemical knowledge, in recent years a greater role was granted to quantum theory in chemistry. The purpose of this paper is not to contribute to the philosophical debate surrounding the status of chemical knowledge. This paper is more concerned about aligning chemistry education with the emerging arguments for granting chemistry a distinct epistemology where models play a key role. In the following section, I will examine how models and modeling have been considered in chemistry education.

MODELS AND MODELING IN CHEMISTRY EDUCATION

There is substantial evidence that children learn and use models from an early age (Schauble, Klopfer & Raghavan, 1991; Scott, Driver, Leach, & Millar, 1993). Children's learning of models in the classroom has been promoted on the grounds that models can act as "integrative schemes" (National Research Council, 1996, p. 117) bringing together students' diverse experiences in science across grades K-12. The Unifying Concepts and Processes Standard of The National Science Education Standards in the United States, for instance, specifies that:

> "Models are tentative schemes or structures that correspond to real objects, events, or classes of events, and that have explanatory power. Models help scientists and engineers understand how things work. Models take many forms, including physical objects, plans, mental constructs, mathematical equations and computer simulations" (NRC, 1996, p.117).

Science as Inquiry Standards emphasize the importance of students' understanding of *how* we know what we know in science. Taken together, these standards suggest it is not enough that students have an understanding of models as such. In other words, acquisition of declarative knowledge or conceptual information on models is only one aspect of learning models. Students need also to gain an appreciation of *how* and *why* these models are constructed. What is implied with the latter standard is that students need to develop an understanding of procedural knowledge within a domain of science that employs models.

In light of the mentioned standards, it is important to evaluate how models have been conventionally treated in the chemistry classroom. When we examine the use of chemical models in teaching, we witness several trends that suggest lack of support for students' understanding of models and modeling. First, chemical models have been presented to students as *final* versions of our knowledge of matter: copies of real molecules in contrast to approximate and tentative representations (Grosslight, Unger, Jay, & Smith, 1991; Weck, 1995). Within the traditional framework of teaching, the motivations, strategies and arguments underlying the development, evaluation and revision of chemical models are overlooked. Classroom teaching typically advances the use of models for conceptual differentiation. For instance, models are used to distinguish weight from density (Smith, Snir & Grosslight, 1992), and temperature from heat (Wiser, 1987).

Second, textbooks often do not make clear distinctions between chemical models (Glynn, Britton, Semrud-Clikeman & Muth, 1989) but rather frequently present 'hybrid models' (Gilbert & Boulter, 1997). Carr (1984) provides the following example which illustrates a common model confusion in textbooks:

> "Since NaOH is a strong base, Na^+ is an extremely weak conjugate acid; therefore, it has no tendency to react with H_2O to form NaOH and H^+ ion." (p. 101)

The first statement is based on the Arrhenius model of acids and bases. The second statement can be interpreted in terms of the Bronsted-Lowry model although the emphasis on ionization is not consistent with this model. When and why a new model is being used, and how this model differs from another model are not typically explicated in textbooks (Carr, 1984).

Third, chemical models have been synonymous with ball-and-stick models which are typically used as visual aids (Grosslight et al., 1991; Leisten, 1994). These 'physical models' have been intended to supplement conceptual information taught, and their use has been justified on Piagetian grounds: that students in concrete operational stages, in particular, need concrete models to understand the structure of molecules (Battino, 1983). The problem with this perspective is threefold:

1. The separation of conceptual information about atoms and molecules from physical models that represent them is inappropriate. Physical models *embody* conceptual information. In fact, their very existence is based on conceptual formulations about atoms and molecules.

2. The focus on chemical models as physical models underestimates the diversity and complexity of models in chemistry. As illustrated earlier, for instance, models of acids and bases are abstract, and each model is accompanied by different sets of premises about what an acid or a base entails.

3. The presumption that students in concrete operational stage *especially* need physical models is simply a weak argument. It is common practice for chemists themselves to use physical models to facilitate their communication and understanding of the structure and function of molecules. What this argument achieves in doing is to stress a deficiency on the part of children's potential to learn.

The fourth trend in the treatment of chemical models in the traditional classroom concerns the shift in emphasis from models to theories since the incorporation of quantum mechanical theories in chemistry. Chemistry and physical science textbooks show a growing tendency to begin with the establishment of theoretical concepts such as the 'atom' (Abraham, Williamson, & Westbrook, 1994; Erduran, 1996). Textbooks often fail to stress the approximate nature of atomic orbitals and imply that the solution to all difficult chemical problems ultimately lies in quantum mechanics (Scerri, 1991).

Finally, traditionally chemical knowledge taught in lectures has been complemented by laboratory experimentation which is intended to provide students with the opportunity to experience chemistry as inquiry. Chemical experimentation, however, has rarely been translated in the educational environment as an activity through which models are developed, evaluated and revised. Rather, experimentation is typically implemented as data collection and interpretation. Evidence suggests, however, that explanatory models may not be generated from data obtained in laboratory activities if explicit construction of such models is not encouraged (Schauble et al., 1991).

Given the trends in the way that models have conventionally been utilized in the classroom, it is not surprising that students' experience difficulties with models (Carr, 1984; Gentner & Gentner, 1983). Understanding of chemical models has been characterized in terms of three levels in students' thinking (Grosslight et al., 1991). At the first level, students think of models as toys or copies of reality which may be incomplete because they were intentionally designed as such.

At the second level, models are considered to be consciously produced for a specific purpose, with some aspects of reality being omitted, suppressed or enhanced. Here, the emphasis is still on reality and the modeling rather than on the ideas represented, as it is the case with the first level understanding. At the third level, a model is seen as being constructed to develop ideas, rather than being a copy of reality. The modeler is active in the modeling process. Few students demonstrate an understanding of chemical models as characterized by the third level. Many students' conceptions of models as representations of reality persist even after explicit instruction on models (e.g. Stewart, Hafner, Johnson, & Finkel, 1992).

It is imperative that more attention is devoted to the effective teaching and learning of chemical models. In particular, omission in the classroom of the heuristics, strategies and criteria that drive knowledge growth, is likely to contribute to chemical illiteracy: a form of alienation where, not fully understanding how knowledge growth occurs in chemistry, students invent mysteries to explain the material world. Concerns have been raised about pseudoscientific interpretations of chemical knowledge (Erduran, 1995) and mystification of chemical practices (Leisten, 1994).

In the classroom, recipe-following continues to be disguised as chemical experimentation - a significant problem often referred to as the 'cookbook problem' (van Keulen, 1995). Chemistry, the science of matter, is not driven by recipes, nor by data collection and interpretation alone. Chemists contribute to the development, evaluation and revision of chemical knowledge. For effective teaching and learning of chemistry, classrooms need to manifest 'what chemists do'. What chemists do is to model the structure and function of matter.

CONCLUSIONS

We come from a tradition in science education which involves handing down of concepts and principles to students without engaging them in the processes of scientific inquiry that make possible the generation of these concepts and principles. In particular, rarely do we see students being facilitated in the formulation, evaluation and revision of scientific knowledge claims. Students' experimentation in the chemistry laboratory, for instance, is conventionally based on rote recipe-following and is not representative of chemical inquiry that underlies what chemists do.

Philosophy of chemistry is a new field that can inform chemistry education about what philosophical themes are crucial to apply in chemistry education and how cgrowth of chemical knowldge can be promoted at the level of the classroom. In particular, in this paper I have used the example of models in chemistry to elaborate on how development, evaluation and revision of chemical knowledge through modeling is central to the science of chemistry and should be manifested in chemistry classrooms. Students will be immersed in growth of chemical knowledge when they are provided with the opportunities to develop and use the very criteria, heuristics and strategies that provoke and validate knowledge claims of chemistry.

Bibliography

Abraham, M. R., Williamson, V. M., & Westbrook, S. L. (1994). A cross-age study of the understanding of five chemistry concepts. Journal of Research in Science Teaching, 31(2), 147-165.

Akeroyd, F. M. (1984). Chemistry and Popperism. Journal of Chemical Education, 61(8), 697-698.

Battino, R. (1983). Giant atomic and molecular models and other lecture demonstration devices designed for concrete operational students. Journal of Chemical Education, 60(6), 485-488.

Bent, H. A. (1977). Uses of history in teaching chemistry. Journal of Chemical Education, 54, 462-466.

Brush, S. (1978). Why chemistry needs history and how it can get some, Journal of College Science Teaching, 7, 288-291.

Butterfield, H. (1949). The origins of modern science. London: G Bell & Sons.

Carr, M. (1984). Model confusion in chemistry. Research in Science Education, 14, 97-103.

Del Re, G., & Liegener, (1987). The relation of chemistry to other fields of science: Atomism, reductionism and reversal of reductionism. Epistemologia, 10, 269-282.

Ellis, P. (1989). Practical chemistry in a historical context. In M. Shortland & A. Warwick, Teaching the history of science. Oxford: Basil Blackwell.

Erduran, S. (1997). Reflections on the proceedings from HPSST conferences: A profile of papers on chemistry education. *Proceedings of International History, Philosophy and Science Teaching Group North and South America Regional Conference*. CD-rom, pp. 252-258. Calgary: University of Calgary.[ERIC Document Reproduction Service No. ED412083]

Erduran, S. (1996, April). Analysis of physical science textbooks for conceptual frameworks on acids, bases and neutralization. Paper presented at the annual meeting of the American Educational Research Association, New York. [ERIC Document Reproduction Service No. ED395791]

Erduran, S. (1995). Science or pseudoscience: Does science education demarcate? The case of chemistry and alchemy in teaching. In, F. Finley, D. Allchin, D. Rhees, & S. Fifield (Eds.), *Proceedings of the Third International History, Philosophy and Science TeachingConference*, Vol. 1, pp. 348-354. Minneapolis: University of Minnesota.

Gentner, D., & Gentner, D. R. (1983). Flowing waters or teeming crowds: Mental models of electricity. In D. Gentner & A. L. Stevens (Eds.), Mental models (pp. 99-129). Hillsdale, NJ: Erlbaum.

Gilbert, J., & Boulter, C. (1997). Learning science through models and modelling. In B. Frazer, & K. Tobin (Eds.), The international handbook of science education. Dordrecht: Kluwer.

Glynn, S., Britton, B. K., Semrud-Clikeman, M., & Muth, K. D. (1989). Analogical reasoning and problem solving in science textbooks. In J. A. Glover, R. R. Ronning & C. R. Reynolds (Eds.), Handbook of creativity (pp. 383-398). New York: Plenum Press.

Green, J. H. S. (1993). What is philosophy of chemistry? In E. Scerri (Ed.), The Philosophy of Chemistry, Report of the meeting held at the Science Museum Library. London: Royal Society of Chemistry Historical Group Society for the History of Alchemy and Chemistry.

Grosslight, K., Unger, C., Jay, E., & Smith, C. (1991). Understanding models and their use in science: Conceptions of middle and high school students and experts. Journal of Research in Science Teaching, 29, 799-822.

Heeren, J. K. (1990). Teaching chemistry by the Socratic Method. Journal of Chemical Education, 67(4), 330-331.

Hendry, R. F. (1993). Quantum chemistry in the ideal world. In E. Scerri (Ed.), The Philosophy of Chemistry, Report of the meeting held at the Science Museum Library. London: Royal Society of Chemistry Historical Group Society for the History of Alchemy and Chemistry.

Herron, J. D. (1977). The place of history in the teaching of chemistry. Journal of Chemical Education, 54(1), 15-16.

Hoffmann, R., & Torrence, V. (1993). Chemistry imagined: Reflections on science. Washington DC: Smithsonian Institute Press.

Jaffe, B. (1938). The history of chemistry and its place in the teaching of chemistry. Journal of Chemical Education, 15, 383-389.

Kauffman, G.B. (1989). History in the chemistry curriculum, Interchange, 20(2), 81-94.

Kauffman, G. B., & Szmant, H. H. (1984). The central science: Essays on the uses of chemistry. Fort Worth: Texas Christian University Press.

Kornblith, H. (Ed.). (1985). Naturilizing epistemology, Cambridge, MA: MIT Press.

Leisten, J. (1994). Teaching alchemy? Chemistry in Britain, 30(7), 552-552.

Luder, W. F., McGuire, W. S., Zuffanti, S. (1943, July). Teaching the electronic theory of acids and bases in the general chemistry course. Journal of Chemical Education, 344-347.

Nagel, E. (1961). The structure of science. New York: Harcourt.

National Research Council. (1996). National Science Education Standards. Washington DC: National Academy Press.

Novak, J. D. (1984). Application of advances in learning theory and philosophy of science to the improvement of chemistry teaching. Journal of Chemical Education, 61(7), 607-612.

Nye, M. J. (1993). From chemical philosophy to theoretical chemistry. Berkeley: University of California Press.

Oppe, G. (1936). The use of chemical history in the high school. Journal of Chemical Education, 13, 412-414.

Partington, J. R. (1957). A Short History of Chemistry (3rd ed.). New York: MacMillan.

Pauling, L. (1985, November 7). Why modern chemistry is quantum chemistry, New Scientist, 54-55.

Plesch, P. H. (1993). Why philosophy of chemistry is different. In E. Scerri (Ed.), The Philosophy of Chemistry. Report of the meeting held at the Science Museum Library. London: Royal Society of Chemistry Historical Group Society for the History of Alchemy and Chemistry.

Primas, H. (1983). Chemistry, quantum mechanics and reductionism. Berlin: Springer.

Pumfrey, S. (1989). The concept of oxygen: Using history of science in science teaching. In M. Shortland, & A. Warwick (Eds.). Teaching the history of science (pp. 142-155). Oxford: Basil Blackwell.

Russell, C. A. (Ed.) (1985). Recent developments in the history of chemistry. Royal Society of Chemistry. Whitstable, Kent: Whitstable Litho.

Sammis, J. H. (1932). A plan for introducing bioraphical material into science cources. Journal of Chemical Education, 9, 900-902.

Scerri, E. (1996). Stephen Brush, the Periodic Table and the Nature of Chemistry. In P. Janich, & N. Psarros (Eds.), 2nd Erlenmeyer Colloquium on the Philosophy of Chemistry. Marburg University, Wurtzburg: Koningshausen & Neumann.

Scerri, E. (1994a). Prediction of the nature of hafnium from chemistry, Bohr's theory and quantum theory. Annals of Science, 51, 137-150.

Scerri, E. (1994b). Has chemistry been at least approximately reduced to quantum mechanics? In D. Hull, M. Forbes, & R. Burian (Eds.). Philosophy of Science Association (Vol. 1, pp. 160-170). East Lansing, MI: Philosophy of Science Association.

Scerri, E. (1991). Chemistry, spectroscopy and the question of reduction. Journal of Chemical Education, 68(2), 122-126.

Schauble, L., Klopfer, L. E., & Raghavan, K. (1991). Students' transition from an engineering model to a science model of experimentation. Journal of Research in Science Teaching, 18, 859-882.

Scott, P., Driver, R., Leach, J., & Millar, R. (1993). Students' understanding of the nature of science (Working papers 1-11). Children's Learning in Science Research Group, Leeds: University of Leeds.

Shortland, M., & Warwick, A. (1989). Teaching the history of science. Oxford: Basil Blackwell.

Smith, C., Snir, J., & Grosslight, L. (1992). Using conceptual models to facilitate conceptual change: The case of weight/density differentiation. Cognition and Instruction, 9, 221-283.

Stewart, J., Hafner, R., Johnson, S., & Finkel, E. (1992). Science as model building: Computers and high-school genetics. Educational Psychologist, 27(3), 317-336.

van Brakel, J. (1994). On the neglect of the philosophy of chemistry. Paper presented at the First International Conference on Philosophy of Chemistry, London.

Paper to be presented at the Fifth History, Philosophy and Science Teaching Conference, Pavia, Italy, September 1999.

van Brakel, J., & Vermeeren, H. (1981). On the philosophy of chemistry, Philosophy Research Archives, 1405-1456.

van Keulen, H. (1995). Making sense: Simulation-of-research in organic chemistry education. Utrecht: CD-b Press.

Wasserman, E., & Schaefer, H. F. (1986). Methylene geometry. Science, 233.

Weck, M. A. (1995). Are today's models tomorrow's misconceptions? Proceedings of the Third International History, Philosophy and Science Teaching Conference (Vol. 2, pp. 1286-1294). University of Minnesota, Minneapolis.

Wiser, M. (1987). The differentiation of heat and temperature: History of science and novice-expert shift. In D. Strauss (Ed.), Ontogeny, phylogeny and historical development (pp. 28-48). Norwood, NJ: Ablex.

Zuckermann, J. J. (1986). The coming renaissance of descriptive chemistry. Journal of Chemical Education, 63, 829.

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Author(s): SIBEL ERDURAN

Corporate Source: Publication Date: KING'S COLLEGE LONDON, 1999 (UK)

PAPER PRESENTED AT FIFTH INTERNATIONAL HISTORY, PHILOSOPHY AND SCIENCE TEACHING CONFERENCE, PAVIA, ITALY SEPTEMBER 1999

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EFF-088 (Rev. 9/97)