# Content Standards for the History and Nature of Science

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## Introduction

**The importance of history in chemical education.** Before the 1950s, the inclusion of the history of science in the teaching of science was commonplace. Unfortunately, this is no longer the case. Possible explanations for this omission include the views that science history is no longer a legitimate subject in science education, that science history does not contribute to learning the technical aspects of science (Brush, 1974), or that it is difficult to fit into the topic loads of current science classes (Matthews, 1994; Rasmussen, 2007). Over the last several decades, however, the history of science has enjoyed a resurgence, along with a growing awareness regarding the important roles it plays in science education:

- History promotes better comprehension of scientific concepts and methods (Matthews, 1994; Schwartz, 1977).
- History illustrates the importance of individual thought and creativity in the development of science (de Carvalho and Vannucchi, 2000; Kauffman, 1987; Matthews, 1994; Schwartz, 1977).
- History of science is intrinsically worthwhile (Kauffman, 1987; Matthews, 1994).
- History is necessary to understand the nature of science (de Carvalho and Vannucchi, 2000; Giunta, 1998; Herron et al., 1977; Kamsar 1987; Kauffman, 1987, 1989; Matthews, 1994).
- History counteracts the dogmatic view of science commonly found in texts and classes (de Carvalho and Vannucchi, 2000; Giunta, 2001; Herron et al., 1977; Kauffman, 1987, 1989; Matthews, 1994; Schwartz, 1977).

- History humanizes the subject matter of science, making it less abstract and more engaging for students (Herron et al., 1977; Kamsar, 1987; Kauffman, 1987, 1989; Matthews, 1994; Schwartz, 1977).
- History shows the connections among chemical disciplines (Kauffman, 1987; Matthews, 1994).
- History allows one to more easily identify pseudoscience (Rasmussen, 2007).

In fact, it can be argued that the history and philosophy of science are an integral part of scientific knowledge and, therefore, must be included in science education (de Carvalho and Vannucchi, 2000). As such, the inclusion of historical and philosophical aspects of science in high school courses has been a key recommendation of science-teaching research studies (de Carvalho and Vannucchi, 2000; Matthews, 1994). This is echoed in content standard G of the *National Science Education Standards* (NSES): "all students should develop [an] understanding of science as a human endeavor, [the] nature of scientific knowledge, and historical perspectives" (National Research Council, 1996).

**The importance of chemistry in the history and nature of science.** Chemistry is often referred to as "the central science" because it overlaps and bridges the other sciences, including those of physics and biology. As such, the inclusion of chemistry in the history of science is especially important. And while the history of science, in general, is important in science education, all too often, these historical inclusions tend to focus on the history of physics or biology, rather than on the history of chemistry. It is thought by some that this is at least partially due to the fact that in comparison to other scientists, chemists display relatively little interest in the history of their own subject, and the general state of research in the history of chemistry is not as strong as that of the history of physics (Kauffman, 1989; Matthews, 1994). Contrary to these views, however, is the fact that numerous authors have championed the inclusion of history of chemistry into chemistry education (Kauffman, 1989). Not only does it give students a greater comprehension and appreciation of chemistry itself, but it also illustrates better than any other scientific discipline how all science, medicine, and technology are intertwined and related (see discussion in ***Chemistry, history, and interdisciplinarity*** below).

## The Proper Use of History in Chemical Education

**The dangers of beautifying or simplifying history.** Introducing historical materials is often done selectively, as the primary purpose is to use these materials to teach modern theories and techniques more effectively. However, overly selective use of history may result in a series of fascinating anecdotes rather than factual history (Brush, 1974). Students may gain no real understanding of the problems that concerned past scientists, the context in which they worked, or how they convinced their contemporaries to accept new ideas (Matthews, 1994).

One dangerous trend along these lines is to start with historical fact, but to then remove all information deemed unnecessary, too confusing, or contradictory to the idea being taught. The problem, however, is that this simplified product now gives students a skewed (if not completely incorrect) view of history. This treatment of history can make it seem that the original discovery or theory was without flaws and that the modern form is identical to the original, or at least in perfect agreement with accepted thought. Although this simplified version is easier for the student to incorporate into the modern chemistry being learned, it removes the important fact that our modern theories and concepts did not develop in a linear, logical style. Simplified versions of history run the risk of furthering the student's misconception that modern chemistry is a finished and absolute product unchangingly etched in stone (Giunta, 2001; Kauffman, 1987, 1989). Such simplified history is commonly found in contemporary textbooks and contributes to a distorted form of scientific history that is more myth and legend than true history (Brush, 1974). If we teach science as the pursuit of truth and fact, should this not also hold true of our treatment of our past heritage as well?

**True history vs. idealized history.** While idealized history may make a more digestible story, it not only gives a false view of history, but also removes a number of opportunities to use history as a powerful teaching tool. A true historical approach that includes all the error, approximation, and human foibles allows students to witness the reality of science at work (Schwartz, 1977). Here, students can see that while intellect and education are important, so too are enthusiasm, optimism, an appetite for hard work, and a bit of luck. Likewise, a true historical approach recognizes imagination and gives students better recognition of their own creative abilities as they learn that intuition, as well as logic, is a legitimate approach to problem solving (Kauffman, 1987; Schwartz, 1977).

One of the concerns expressed about exposing students to true history, rather than an idealized, sanitized version, is that it may turn impressionable students away from chemistry by letting them see that chemists do not always behave as rational, open-minded investigators who proceed logically, methodically, and unselfishly toward the truth (Kauffman, 1989). In particular, by taking an open, honest look at some of the most revered figures in chemistry, we may somehow tarnish their reputations and reduce students' admiration for these scientists and their accomplishments (Schwartz, 1977). However, one could argue that this is just as valid a reason to include the full, honest truth in history. As educators, it is becoming more and more common to witness students begin their study of science with the attitude that there is no way that they can master the subject. Such students feel that such accomplishments are far too hard for a "normal" student such as themselves and that to succeed in science requires exceptional intellectual abilities. Recognizing that great figures of chemistry were human beings with strengths and weaknesses not all that different from themselves can give students the confidence to try. For such students, true history can illustrate the number of times great discoveries have been made by those with average abilities, poor training, or faulty logic and can, just as importantly, show that such discoveries are rarely made by one scientist alone, but that such accomplishments were also dependent on the work, theories, and insight of other contributing scientists.

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## Science as a Human Endeavor

**Humanizing science.** The primary goal of NSES content standard G is that all students should develop an understanding of science as a human endeavor (National Research Council, 1996). This is important to counteract the sterile, cold image often associated with science. Students are typically more receptive to the subject when they can visualize people in science. The application of the historical approach, with its emphasis on people and society, can be an excellent tool to place chemistry in perspective as a human activity (Herron et al., 1977). As stated by Jaffe (1955), history can show that "Inextricably tied to these world-shaking advances was an even greater story—the human one—the saga of men [*sic*] groping for causes and struggling to frame laws; of men [*sic*] leading intellectual revolutions and fighting decisive battles in laboratories. Here was meaning, light, inspiration, life."

Illustrating the diversity of scientists and the international character of science is crucial to emphasize in teaching about science as a human endeavor (Jaffe, 1955; Kauffman, 1989). Teachers must be careful to use historical materials that undermine, rather than reinforce, the tendency of many students to view science as a product of men from the United States and Europe. The very words from Jaffe (1955) quoted above limit that enterprise to men. Many works of history of chemistry do, in fact, emphasize the achievements of men of European descent, because social factors limited the participation of women and of many non-European ethnic groups in science. Intellectual honesty requires acknowledgment of this historical reality, whose effects still influence the present. In light of this reality, selecting examples of women and other underrepresented groups who made significant contributions to chemistry despite disadvantages, is vitally important. The Eurocentric male view can, and should, be dispelled as students come to understand that no gender, country, or culture has a monopoly on discovery (Kauffman, 1989) and that many of chemistry's greatest discoveries originated in the Middle East, Egypt, and Asia.

**The biographical approach.** One of the easiest methods to convey science as a human endeavor is through the biographical approach, which can also be one of the most inspiring to students (Kauffman, 1989). The benefits of a biographical approach in teaching chemistry have been widely recognized (Kauffman, 1971), and there are a number of possible methods for incorporating scientific biography into chemistry classes. Short biographical statements are often included in textbooks, and, while they are typically examples of idealized history as discussed above, they offer a simple starting point to introduce a particular scientist. The life and work of the scientist can then be viewed in more depth through classical lecture or teacher-led discussion (Jaffe, 1955) or can lead to student-oriented projects, including short dictionary/encyclopedia-style writing assignments (Jensen, 2001), term papers (Kauffman, 1971), class presentations, or even cooperative group research projects and presentations (Carroll and Seeman, 2001). The biographical approach also has the benefit of availability of an abundance of quality resources, including standard texts (Bowden, 1997; Jaffe, 1976), online databases and biographies (Burda, 2008; Burke, 2008; Mainz, 2008; Nobel Foundation, 2008; Chemical Heritage Foundation, 2008) and video sources (Djerassi and Hoffmann, 2003; Smith et al., 2007).

## History and the Nature of Scientific Knowledge

**Chemistry, history, and interdisciplinarity.** Whereas science as a human endeavor appears as a content standard throughout K–12 education, standards on the nature of science do not appear until the middle grades. Fortunately, this is still before students begin to take disciplinary science courses. Interdisciplinarity is an increasingly important aspect of the current practice of science, so it is desirable that students start to encounter material on the nature of science before the idea of distinct scientific subjects becomes ingrained. As students learn about the nature of scientific inquiry (observation, experimentation, and the like) and the vast range of phenomena to which these methods of inquiry can be applied (plants, planets, pendula, and many, many more), the world of science appears without disciplinary boundaries. Eventually, students learn about scientific disciplines—and for good reason. Specialization is inevitable in science education, and those students who continue to study science in college and beyond will be exposed to ever more of it. Yet even as students begin to be exposed to distinct scientific specialties, it is worth pointing out that nature respects no disciplinary boundaries and that much contemporary science is done by interdisciplinary teams.

Much of the instruction on the nature of science can and ought to be done through hands-on activities (see chapter 4 on inquiry learning and chapter 7 on laboratory instruction). Historical material can also be profitably employed. Biographical materials that illustrate science as a human endeavor can also represent science as an interdisciplinary endeavor. Because chemistry (the "central science") has long shared borders with several scientific disciplines, there are many examples of scientists who contributed to chemistry as well as other scientific fields.

The individuals who made important contributions to chemistry include numerous examples of physicians, geologists, physicists, and those scientific generalists of yesteryear, natural philosophers. Antoine Lavoisier contributed significantly to physiology as well as chemistry. Henry Cavendish both discovered hydrogen and determined the mass of Earth. John Dalton formulated an atomic theory of matter and described color blindness (from personal experience). Ernest Rutherford, who disparaged sciences other than physics, received a Nobel Prize in chemistry. These historical examples illustrate that the permeability of scientific boundaries is not a modern phenomenon. They provide historical precedent for the multidisciplinary fields in which today's chemists participate—areas such as energy, materials, biotechnology, climate change, and nanotechnology.


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**Case studies in how science works.** Historical material can shed light on other aspects of the nature of science besides interdisciplinarity. It is worth emphasizing to students that the importance of empirical testing in science does not imply a single "scientific method," let alone a method that precludes imagination, creativity, passion, or luck (see chapter 3 on unifying themes, particularly its treatment of evidence, models, and explanation.). Even though observation and experiment are what ultimately lead to acceptance by the scientific community, there are almost as many sources of scientific ideas, explanations, analogies, and questions as there are scientists. Derry's *What Science Is and How It Works* (1999) is a good primer for science teachers on the nature of science, and it treats several historical cases, including some in chemistry. The role of luck in science is emphasized in Roberts' *Serendipity: Accidental Discoveries in Science* (1989), a worthwhile book for both instructors and older students.

Scientists' descriptions of their own discoveries can also shed light on the nature of science. First-hand descriptions must be carefully selected (and often annotated or supplemented) to be understandable by students and useful in the classroom. Such accounts can reveal the relationship between what an investigator observed and what he or she concluded, and they can also reveal lines of inquiry (fruitful and otherwise) prompted by a preliminary observation, and even instances of speculation that proved to be mistaken or fortuitous. Some of the annotated papers in the "Elements and Atoms" portion of the Classic Chemistry Web site (Giunta, 2008) are suitable for high school students. The descriptions of Lavoisier's work on the nature of water and Becquerel's experiments on penetrating rays from uranium salts (i.e., radioactivity) are sufficiently clear, rich, and brief to warrant close reading. Tracing the evolution of some chemical concepts can shed light on current understanding of those concepts. Atomic structure is certainly a topic amenable to a "history of ideas" treatment: seeing successive models incorporate new knowledge as it became available both illustrates how scientific knowledge can be constructed and highlights the evidence behind our current understanding.

## Historical Perspectives

**Chemistry and society.** Historical perspectives on science can illustrate the pervasiveness and variety of interactions of science and technology with social, political, and economic history. Issues of science and society necessarily encompass interdisciplinary approaches writ large. That is, we are no longer talking about interdisciplinarity simply within natural science but between natural science, social science, and the humanities. We hope that teachers of all of these subjects will point out relevant connections to the other subjects. Because our readers are chemistry teachers, we limit ourselves to connections they can make to other subjects; at the same time, we encourage chemistry teachers to work with their colleagues in other subjects to mutually reinforce these connections.

Chemists are, understandably, concerned with the public image of their profession. The persistent association of chemistry with pollutants and other hazardous materials presents a stark contrast to the vision statement of the American Chemical Society (Raber, 2006), "Improving people's lives through the transforming power of chemistry." Chemistry teachers can show chemistry as a relevant and beneficial enterprise by providing examples of how it affects society past and present (see chapter 8). However, in providing a beneficent view of chemistry, the temptation to gloss over real problems must be avoided (see ***True history vs. idealized history*** above). Balanced accounts are both more interesting and more intellectually honest than simplistic accounts that portray chemists as heroes or villains.

One particularly rich episode from 20th-century chemistry involves chlorofluorocarbons (CFCs) and the ozone layer. Chemists play pivotal roles throughout this story, from the invention of CFCs as nontoxic and nonflammable refrigerants, to detecting alarming quantities of them still in the atmosphere years after their release, to unraveling the complex interactions that cause CFCs eventually to catalyze destruction of ozone in the stratosphere. An additional feature that makes this story a particularly relevant case of science and society is the ultimate action of governments around the world to regulate the hazard. In short, chemists made the problem, chemists identified the problem, and chemists provided governments with information that permitted solution of the problem.

Interactions between chemistry and society need not have such global significance to capture students' attention, though. Multiple connections can be made between chemistry and the ostensibly more "creative" field of art. Chemistry, of course, is responsible for the materials artists use today (and in some cases, have used for centuries) to give shape and color to their visions. Pigments, sculpting media, and conservation and restoration of art objects are topics that lie at the intersection of chemistry, art, and history. Kafetzopoulos et al. (2006) describe hands-on activities that link chemistry and art. Kelly et al. (2001) describe an interdisciplinary college course that bridges art and science; their article contains references that can be useful in the high school classroom as well.

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**Teaching history and teaching through history.** Although history of science is itself a prominent part of one of the National Science Education Standards, science teachers strive to impart information and interest in science. Thus, many consider historical material to be supplemental enrichment at best and a distraction at worst. There are, however, several ways to include historical material in the service of learning objectives more directly related to chemistry content and problem solving. One such way was hinted at in the previous paragraph: material that stimulates students' interest in chemistry can motivate the effort and attention required to master chemistry content. Art may attract some students while glamour, sex, or crime may attract others. Although some of these subjects ought to be broached carefully, there are excellent popular books on chemical aspects of such subjects that have the capacity of capturing the interest of some adolescents—and adults as well (Emsley, 2004, 2005).

Stimulating interest serves chemistry learning objectives indirectly. Historical material can also be used in direct support of chemistry content and problem-solving skills by basing quantitative problems on historical data. When teaching Boyle's law, for example, Boyle's data can be displayed, plotted, and fit. When teaching how to determine empirical formulas on the basis of chemical analysis, data from one of the classic 19th-century analytical chemists can be employed. A set of quantitative exercises based on historical data developed mainly for introductory college chemistry can be found as "Classic calculations" at the Classic Chemistry Web site (Giunta, 2008), and some of these can be used or adapted for use in high school.

## Conclusions

We hope that the above discussion and arguments bring to light both the importance of the inclusion of the history of chemistry in chemistry education and many of the ways that this can be accomplished. The incorporation of historical anecdotes in a standard chemistry course can make the course more interesting and relevant—especially for nonscience students (Herron et al., 1977). In addition, the time taken in the classroom for the addition of chemical history provides a "thinking floor" for future chemists to find their place in society and, most importantly, creates interest and provokes thought about the scientific endeavor for the majority of pupils who will not become scientists (Kamsar, 1987). If we want our students to have a real conceptual understanding of scientific progress and practice, then we must go beyond the regurgitation of experimental details (Niaz and Rodriguez, 2001); the use of history allows us to accomplish this goal while providing a richer learning environment for our students.

### Recommended Readings

Derry, G. N. *What Science Is and How It Works*; Princeton University Press: Princeton, NJ, 1999. Addresses many facets of the nature of science, including several historical cases, some in chemistry. Aimed at college nonscience majors, so suitable for teachers and education students.

Emsley, J. *Vanity, Vitality, and Virility: The Science Behind the Products You Love to Buy*; Oxford University Press: New York, 2004. Chemical aspects of selected cosmetics, personal care products, dietary supplements, and drugs described for a general audience.

Emsley, J. *The Elements of Murder*; Oxford University Press: New York, 2005. Toxic chemical elements and their uses and abuses over the years, described for a general audience.

Jaffe, B. *Crucibles: The Story of Chemistry, From Ancient Alchemy to Nuclear Fission*, 4th ed., Dover: New York, 1976 (first edition 1930). A set of biographies of famous chemists. In its day, it was popular and award-winning for humanizing chemists; the absence of women and other underrepresented groups in its pages is a shortcoming.

Kafetzopoulos, C.; Spyrellis, N.; Lymperopoulou-Karaliota, A. The Chemistry of Art and the Art of Chemistry. *J. Chem. Educ.* 2006, *83,* 1484–1488. Describes hands-on classroom activities that connect chemistry and art.

Kelly, C.; Jordan, A.; Roberts, C. Finding the science in art. *J. Coll. Sci. Teach.* 2001, *31,* 162–166. Describes an interdisciplinary college course that bridges art and science; its references can be useful to the high school classroom as well.

Matthews, M. R. *Science Teaching, The Role of History and Philosophy of Science*; Philosophy of Education Research Library; Routledge: New York, 1994. Excellent review of using the history and philosophy of science in science education.

Ringnes, V. Origin of the names of chemical elements. *J. Chem. Educ*. 1989, *66,* 731–736. Source of interesting historical information on the elements.

Roberts, R. M. *Serendipity: Accidental Discoveries in Science*; Wiley: New York, 1989. Source of anecdotes that illustrate how luck can be an important ingredient in discoveries and inventions.

### Recommended Web Sites and Other Media

The intersection of history of chemistry and chemical education is an area to which high school teachers can contribute, and the Internet makes it easier to distribute that work. One of the first Internet sites to republish classic historical papers, and still one of the richest, was created by a chemistry teacher, John Park. A more recent Web site devoted to discoveries and names of the chemical elements was prepared by another high school teacher, Dave Trapp, based on an article by Vivi Ringnes (1989).

Bowden, M. E. *Chemical Achievers: The Human Face of Chemical Sciences*; Chemical Heritage Foundation: Philadelphia, 1997; Web version can be found at http://www.chemheritage.org/classroom/chemach/index.html (accessed March 18, 2008). Pictures and short biographical sketches of prominent chemists. Underrepresented groups are included, but not as a primary emphasis.

Burda, G. A., Ed., Women in Chemistry: Her Lab in Your Life. http://www.chemheritage.org/women_chemistry/index.html (accessed March 18, 2008). Biographical sketches of women in chemistry, past and present.

Burke, B. A., Ed., JCE Online: Biographical Snapshots of Famous Women and Minority Chemists. http://jchemed.chem.wisc.edu/JCEWWW/Features/eChemists/index.php (accessed March 18, 2008). Biographical sketches of women in chemistry and chemists from ethnic minorities.

Chemical Heritage Foundation. Science Alive: Percy Julian. http://www.chemheritage.org/scialive/julian/index.html (accessed March 18, 2008). Classroom materials and exercises based on the life and work of a 20th century African American chemist.

Djerassi, C.; Hoffmann, R. Oxygen [DVD]; Wisconsin Initiative for Science Literacy, 2003. Recorded production of a play about the discovery of oxygen that explores questions of credit and motivation; written by two prominent chemists; a teacher's guide is also available.

Giunta, C. J. Classic Chemistry. http://web.lemoyne.edu/~giunta/ (accessed March 18, 2008). "Elements and Atoms" section contains papers annotated to illustrate process of discovery; "Classic Calculations" includes quantitative exercises based on historical data.

Mainz, V. Chemical Genealogy. http://www.scs.uiuc.edu/~mainzv/Web_Genealogy/ (accessed March 18, 2008). Database of chemical researchers' scientific "lineages," illustrating mentor-student connections and influences. Each entry contains a short biography with references to additional information.

Nobel Foundation. All Nobel Laureates in Chemistry. http://nobelprize.org/nobel_prizes/chemistry/laureates/ (accessed March 18, 2008). Biographies of Nobel laureates in chemistry and descriptions of their work, including descriptions in their own words and some classroom materials.

Park, J. ChemTeam: Classic Papers Menu. http://dbhs.wvusd.k12.ca.us/webdocs/Chem-History/Classic-Papers-Menu.html (accessed March 18, 2008). Primary sources of many classic chemical discoveries in the words of the original researchers.

Smith, L.; Lyons, S.; Quade, D.; Santiago-Hudson, R.; Vance, C. B. *Forgotten Genius* [DVD]; WGBH, 2007. Features the life and work of 20th-century African-American chemist Percy Lavon Julian.

Trapp, D. Discovery and Naming of Chemical Elements. http://homepage.mac.com/dtrapp/Elements/elements.html (accessed March 18, 2008). Source of interesting historical information on the elements.

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Burke, B. A., Ed., JCE Online: Biographical Snapshots of Famous Women and Minority Chemists. http://jchemed.chem.wisc.edu/JCEWWW/Features/eChemists/index.php (accessed March 18, 2008).

Carroll, F. A.; Seeman, J. I. Placing Science Into Its Human Context: Using Scientific Autobiography to Teach Chemistry. *J. Chem. Educ.* 2001, *78*, 1618–1622.