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Commentary

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How Did We Get Here? Teaching Chemistry with a Historical Perspective

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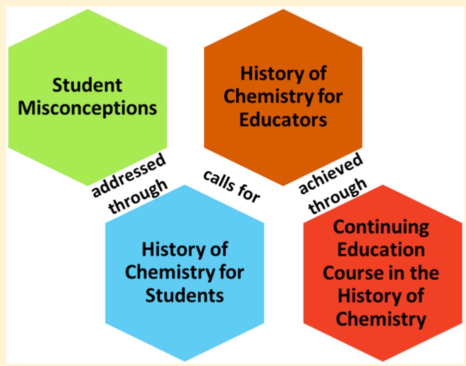
Supporting Information

ABSTRACT: Many students have misconceptions about how chemistry knowledge is generated. These misconceptions can be addressed by highlighting how chemistry knowledge has developed over time. To effectively accomplish this, science educators must be well-versed in the history of chemistry. In this paper, we describe topics that could be covered in a continuing education course for secondary level science educators that centers on the history of chemistry. We hope to stimulate discussions across chemistry departments to encourage our colleagues to offer such courses to in-service secondary science teachers. A history of chemistry course will allow teachers to meet the learning needs of their students. When teachers can explain how chemists made discoveries, overcame obstacles, collaborated with colleagues to answer complex questions, and built upon one another's ideas, students are presented with a realistic picture of scientific research, hence strengthening their understanding of the nature of science.



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Fresh out of college, one of the authors (K.A.O.) became a chemistry teacher in a high school defined by high truancy rates, low math skills, and poor attitudes toward science. Unprepared for these conditions, the first unit K.A.O. taught was a disaster mired in students' mathematical misadventures and repeated failures to synthesize information from data collected during laboratories. To avoid a repeat disaster, K.A.O. supplemented the mathematical and conceptual rigor of the equilibrium unit that followed with the rich and varied history of Fritz Haber. After a short introduction featuring brief film clips, students broke into five specialized groups as part of a cooperative jigsaw activity. Each group studied and discussed one aspect of Haber's life: (1) nitrogen fixation, (2) Clara Haber, (3) chemical warfare, (4) Nobel Prize, and (5) Haber's Jewish heritage. Next, the students formed "home" groups featuring one member from each specialist group to share information and form a complete snapshot of Haber's life. Their final objective was to create a concept map exploring the many facets of Haber's life such as what allowed him to discover the fixation of nitrogen, what motivated him to engage in chemical warfare, and why his Nobel Prize was so contested by his colleagues in the scientific community. Many students who had previously not participated significantly in class became animatedly engaged in defending Haber's right to the Nobel Prize and describing the importance of nitrogen fixation and the chemistry behind Haber's discovery. In addition, these students described the implications of Clara Haber's stunted career and tragic life by drawing on historic and contemporary references to challenges faced by women in science. This history of chemistry project breathed life into what could have been a mathematically driven unit and allowed all students to embrace the relevance and importance of chemical equilibrium.

As this vignette illustrates, chemistry teachers can help their students move beyond mastering discrete facts by encouraging them to examine how chemists develop and use models. A student may know that an atom has a dense center containing protons and neutrons called a nucleus and that electrons exist in clouds with specific shapes around the nucleus. However, it is equally important for him or her to be able to explain how scientists know that there is an incredibly dense center. If students can describe the accepted model, featuring protons

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and neutrons in the center, and how this model originated, they are more likely to demonstrate an understanding of the nature of science and scientific reasoning.[1] To help prepare science teachers so that they can support scientific thinking as outlined by the *Next Generation Science Standards*, we propose the importance and potential topics of a course for in-service and preservice teachers presenting history of chemistry.[2] To avoid confusion in this paper, we use the word "students" only to refer to secondary students; secondary educators in the proposed history of chemistry course will be referred to as teachers, educators, or course participants.

■ STATEMENT OF PROBLEM AND PROPOSED SOLUTION

Research indicates that secondary students do not know how theoretical and practical understanding of chemistry develops and that teachers are unfamiliar with this content or how to teach it.[3,4] However, both the National Research Council and the committee of scientists and science educators who collaboratively developed the *Next Generation Science Standards* emphasize the need for students and educators to understand the origin of scientific knowledge, calling for integration of science practices along with content knowledge.[1] The *Next Generation Science Standards* further call for instruction in the nature of science (NOS) to help students appreciate scientific practices and how scientific discoveries are made.[2] NOS refers to the practices of science, including the many methods—involving both inductive and deductive reasoning—involved in scientific studies, the social and collaborative nature of research, and the uncertainties and biases that scientists must acknowledge.[1,2] Despite the calls for reformed curricula, teachers are neither necessarily educated in this content nor do they know how to teach it, which makes it difficult to achieve such goals.[4,5]

We propose that educating practicing teachers on the history of chemistry will better prepare them to integrate both history and content into chemistry courses and teach their students how past scientific findings informed subsequent experiments in chemistry. Through case studies and interesting anecdotes, teachers can make chemistry come alive; simultaneously, they can emphasize the years of effort that scientists required to understand how and why chemical phenomena occur. The integration of history of chemistry into the curriculum for secondary science students can result in significantly improved student attitudes about science and higher knowledge about the NOS relative to a comparison group.[6]

First, teachers must feel prepared to teach the history of chemistry. However, many teachers lack familiarity with the history of chemistry and how to use it to reinforce NOS in their teaching.[5] In fact, Cachapuz and Paixoa claim that many teachers view science exclusively as a definitive well-established body of knowledge, emphasizing terminology rather than understanding the scientific principles and relationships, which the authors attribute to the absence of formal education in the history, philosophy, and sociology of science.[4] Lavach found that when integrating historical aspects of science teaching during an in-service program, science teachers improved their understanding of NOS.[7] Additionally, the opportunity to reflect, discuss, and participate in course activities based on historical controversies enhances teachers' understanding of NOS.[8] Padilla found that teachers further benefited from refining their scientific conceptions and learning the epistemology of scientific concepts.[9] Because neither institutions of higher education nor school district professional development institutes in our region typically offer courses covering history, philosophy, and sociology of science, we propose a design for a history of chemistry course for science educators that can be presented as an independent course or modified by university or continuing education instructors and selectively integrated into existing courses.

Course on the History of Chemical Discoveries

We believe a history of chemical discoveries course should be designed and offered to in-service and preservice science teachers to provide a comprehensive review of the chemical discoveries and the historical context in which chemists made them. This course should explore how chemistry theories are created and revised, thus reinforcing the NOS. When teachers know the history of chemistry, they are better prepared to "(1) enrich the presentation of scientific knowledge and (2) emphasize the tentative nature of scientific knowledge."[10] Inclusion of this content in the new national standards warrants relevant training and professional development to assist teachers to meet these standards. Hence, we appeal to our colleagues to develop and implement similar courses for secondary level science educators seeking to fulfill professional development requirements through coursework or pursuing an advanced degree. In this manner, teachers can meet both their licensure requirements and standards outlined by the *Next Generation Science Standards*.

The course objectives should be measurable and promote higher-order thinking. After successfully completing this course, history of chemistry course participants should be able to

(1) Examine cultural values and their influence on chemistry research in different historical periods.
(2) Discuss the socio-political implications of chemistry research and development of chemistry knowledge throughout history.
(3) Analyze the impact of human interactions (rivalries, friendships, greed, sexism, etc.) on scientific endeavors.
(4) Explain how chemistry has altered history and predict how it will continue to do so in the future.
(5) Identify how and why technologies are rapidly integrated into daily life by comparing past and present integrations of technology and predicting future integration.

Course Objectives

Course content should survey an array of chemistry throughout history. We provide an example course overview with suggested units and topics (Table 1). This list provides an example of possible topics for a history of chemistry course or modules to be integrated into a pre-existing course. We recognize that it is not an all-inclusive list of topics. Additionally, if course instructors find the topic list too lengthy for their course design, they can choose to concentrate on a subset of issues. Course objectives can be achieved through discussion of a variety of topics drawn from the history of chemistry. Ultimately, instructors will select specific topics and examples; however, we urge instructors to be thoughtful about what case studies they choose in an effort to present an objective and nonbiased view of history. We chose the following topics to illustrate the historical context of seminal chemistry research, reflect the relationship between scientific revolutions and social history, and explore as case studies appropriate for secondary school science curricula.

We provide a full schedule that could be used or modified in Table S1 including an overview of topics as well as questions

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Table 1. History of Chemistry Course Overview. For Guiding Questions, See Supporting Information

Unit	Suggested Topics
Ancient Alchemy	Alchemy in the East: China, India, and Japan
	Alchemy in the West: The Roman Empire and Medieval Europe
Early Chemistry	Boyle and Starkey, Priestly, and Cavendish
	Phlogiston and ether
	Lavoisier, Avogadro, Mendeleev
Organic Synthesis	Synthetic dyes and pharmaceuticals
	Determining structure and function: Chirality, benzene, DNA, etc.
Inorganic Chemistry	Blomstrand-Jorgensen Chain Theory vs Alfred Werner and Coordination Theory
	Fritz Haber/Nitrogen Fixation
Physical Chemistry	Rivalries in Chemistry
	Nuclear Chemistry: Marie Curie and the Manhattan Project
The Chemistry of War	World War I
	World War II
	The Cold War
Science and Technology in the Modern Age	Chemistry in Daily Life

intended to guide discussion. Major themes of the course should inform discussion questions and include the NOS, effect of sociopolitical climate and culture on NOS and generation of chemistry knowledge, interplay between historical events and scientific developments, and influence of human interactions on the scientific process. Specifically, these themes investigate how changes in thinking lead to changes in actions (i.e., scientific study) and eventual changes in context, ultimately leading to another change in thinking. Science teachers may believe that scientific investigations were progressive and that all findings "advanced" the discipline of chemistry; however, in a history of chemistry course, they will learn that scientific discoveries have not always followed that heuristic.[10] Exploration of this content will assist science teachers to incorporate these important themes in their own high school chemistry curricula.

Pedagogical Strategies

Professional development courses for teachers should model effective pedagogical practices that are consistent with information about how people learn and strategies that support learning.[1] On the basis of a review of the science education literature, effective instructional strategies for a history of chemistry course include interactive lectures, class discussions, Socratic method and questioning, conceptual models, responsive reading, peer reviews, and graphic organizers. We include complete description of these strategies in the Supporting Information (Table S2). Clearly, instructors should employ pedagogies that make the most sense for the learning context, the course participants, and the instructor's instructional philosophy.

Assessment

Modeling effective assessment strategies is essential and necessary to support learning.[1] Using the "backward design" model, instructors can intentionally craft assessments to ensure that they are meaningful and in alignment with learning objectives.[11,12] Assessment of the learning objectives should focus on high-level cognitive skills as described in Bloom's taxonomy, within which lower cognitive skills (knowledge and comprehension) can be embedded.[11] Exams, presentations, and essays are all appropriate assessments of skills when properly constructed and integrated throughout the course.[12] Authentic assessments, however, which allow course participants to analyze, synthesize, and evaluate past chemical discoveries, will enable them to consider how they can integrate similar high-level assessments in their own curricula. An example of an authentic history of chemistry assessment is a part of an activity for which participants must role-play individuals involved in selecting a Nobel Prize winner in chemistry. For this activity, participants would conduct document analysis, develop persuasive, evidence-based arguments regarding nominees, and then find consensus to select an award recipient. Course participants would experience reading both primary research and review articles and then organize historic and scientific evidence about award nominees. The persuasive arguments constructed by and reviewed by participants would serve as summative authentic assessments.

Suggested Supporting Text Resources

We suggest several texts for the course (Table 2), selected to serve two purposes: (1) to provide course participants with some of the knowledge and background necessary to consider themes in the course and (2) to offer case studies that teachers can integrate in their secondary chemistry courses. Because of the large amount of material written on the history of chemistry, this list is not exhaustive; however, the listed texts cover a multiplicity of material and reflect course themes. We encourage instructors to add supplemental texts and readings to better achieve course objectives. We include discussion of the strengths and weaknesses of these texts in the Supporting Information (Table S3).

Table 2. Suggested Texts for a Continuing Education Course on History of Chemical Advances

Suggested Texts
Coffey, P. *Cathedrals Of Science: The Personalities and Rivalries that Made Modern Chemistry*; Oxford University Press: New York, 2010.
Couteur, P. L.; Burreson, J. *Napoleon's Buttons: 17 Molecules that Changed History*; J P Tarcher/Penguin: New York, 2004.
Kean, S. *The Disappearing Spoon*. Back Bay Books/Little, Brown and Company: New York, 2010.
Kuhn, T.S. *The Structure of Scientific Revolutions*, 3rd ed.; University of Chicago Press: Chicago, IL, 1996.

■ CONCLUSION

Student misconceptions regarding the origin of chemistry knowledge can be addressed through instruction in the history of chemistry. Moreover, students can gain a stronger overall understanding of the nature of science if allowed to explore and learn about science discoveries from a historical perspective. Hence, educating teachers about the history of chemistry will enable them to explain how scientific theory and practice have developed over time. The ideas described here propose a strategy for preparing practicing teachers to add historical events and perspectives to their classrooms, thus enhancing student learning of chemistry.

■ ASSOCIATED CONTENT

Supporting Information

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Suggestions for a history of chemistry course including a course overview; instructional strategies recommended for this course; strengths and weaknesses of the suggested texts (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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