Teaching THE Stories OF Scientists AND THEIR Discoveries

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Including the history and nature of science adds understanding to science classes

For many science students and teachers, the history of science brings to mind musty portraits of long-ago chemists, physicists, and biologists, birth and death dates, and some brief mention of specific contributions. Frequently lost amid teaching pressures are the lessons that may be found in the history of science. These stories not only teach students about how science functions, but also can add texture, richness, and understanding to science classes.

It takes very little extra time and effort to correlate required science concepts with history. For example, teachers can provide the historical background for Mendeleev's development of the periodic table as students learn the concept of periodicity. This combined approach focuses student attention not only on the structure of the modern table, but also on the thought process Mendeleev used to arrange the elements.

Students can also perform laboratories that relate to historically significant events, such as in the investigation of aspirin. This kind of student inquiry provides the context of an actual problem, current or past, and gives students opportunities to develop their lab skills.

Finally, students can produce biographies of famous (or not-so-famous) scientists and present them to the class. Students can hone their research skills by investigating the lives of famous scientists and producing personal snapshots.

The power of stories

Learning about the history of science can lead to a deeper understanding of the nature of science itself. In much the same way that philosophy, sociology, and psychology add to our understanding of how science operates, so too can accounts of discovery and discoverers. These accounts provide students with a more complete picture of the human element of science, while at the same time both provide a context for the discovery and help engage students in ways that extend far beyond the communication of mere facts.

In working with teachers, we have found that the main roadblocks to including the history of science are the time pressures associated with curriculum coverage and preparation for statewide tests, along with difficulty in finding high-quality resources. This article has been developed to address at least this last issue. Most of our resources have been developed for high school chemistry classes, but they can easily be adapted for other educational settings.

Activities that include science history and biography provide glimpses of real scientists in action and show students that science is conducted by real people, people with whom students might share a common background or interest. Telling stories is a high-interest way of conveying a concept. By using a wide variety of biographies and histories—particularly those featuring minorities and women—teachers can stimulate student interest, provide role models for all students, and generally give a more complete picture of the nature of scientific work.

Sharing stories of scientists draws students into the underlying science concepts. "Because many concepts involve knowledge about particles students will never see, seeking foundations for 'how we know' through review of classical chemistry investigations is very valuable" (Texley and Wild 1996, 68). As students investigate the lives and accomplishments of scientists, they discover more about inquiry and the authentic nature of knowledge production in science.

Recreating the periodic table

As chemists continued to learn about the properties of the more than 60 elements known by the mid 1800s, there was increasing interest in developing a system to organize this new information. From Prout in 1815, to Newlands in 1866, to Meyer in 1869, scientists in seven different countries advanced more than 15 methods of organizing the elements. Most of these attempts relied on atomic masses.

In 1860, the young Italian chemist Stanislao Cannizzaro presented the first fairly accurate measurements of the elements' atomic masses at an international conference in Germany. Another young chemist, Dmitri Mendeleev, had come to the conference from his home in Russia. Mendeleev had been gathering data on the chemical elements from many other chemists of his time. Using his accumulated data and Cannizzaro's reliable atomic masses for the known elements, Mendeleev recorded properties of the elements on cards. He began to look for patterns believing that "it is the function of science to discover the existence of a general reign of order in nature" (Posin 1948, 167). Mendeleev's success in organizing the periodic table can be used to remind students that both imagination and insight are qualities often found in successful scientists.

Mendeleev's method

With the following activity, students learn about Mendeleev's development of the periodic table and the structure of the modern table. This activity is an example of infusing traditional science content development with its related historical foundation. The activity works best if students can observe properties of the elements for themselves; either from samples of the elements handled safely, high-quality photos, or written descriptions. The first part of this activity involves students looking for patterns in the properties of elements; the second part is a teacher-led discussion that summarizes the history of Mendeleev's table and also develops concepts related to the modern table.

Working in teams, students can observe the properties of individual elements. Students then prepare an indi-

FIGURE 1

A. Sample element card for student use. **B. Sample element card for teacher use.**

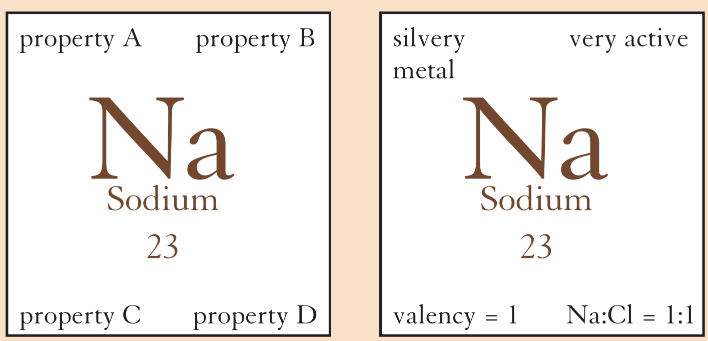

FIGURE 2

The beginning of Mendeleev's table. Elements are grouped based on their similar properties.

Li 6.9	**Be** 9.0	**B** 10.8	**C** 12.0	**N** 14.0	**O** 16.0	**F** 19.0
Na 22.9	**Mg** 24.3	**Al** 26.9	**Si** 28.1	**P** 30.9	**S** 32.0	**Cl** 35.5
K 39.1	**Ca** 40.1					

vidual card for each element in a standard format designated by the teacher (Figure 1A, p. 47). Student groups arrange the cards and look for patterns as a class. (Alternatively, teachers may prepare in advance a complete set of cards for each group of students to allow more time for organizing the cards in a process similar to Mendeleev's.)

As students group the elements, teachers should ask them to explain the evidence on which they base their groupings. It is not necessary at this stage that the groupings are the same as those on the modern periodic table—the process is the important aspect. Class discussion should focus on comparing how students arranged the elements to how Mendeleev arranged them.

Once students have grouped their elements, students can further develop both the science and the history of the periodic relationships among the elements. For this, teachers will have to prepare complete sets of cards for the first 54 elements like the example shown in Figure 1B, p. 47. Additional properties are added to each card, but only those known in 1869 and relied on by Mendeleev—the physical description of each element, its chemical activity, and its valency (the number of bonds it is able to form), in addition to the atomic mass (Figure 1B). The noble gases are absent from Mendeleev's table (and this activity) because they had not yet been discovered.

The teacher should ask students to begin by placing the first seven cards (lithium-to-fluorine) in a horizontal row, in order of increasing atomic mass. Noting the similarity between the properties listed on the sodium and lithium cards, students then place sodium under lithium and create a second horizontal row for the next seven cards, from sodium-to-chlorine, under the lithium-to-fluorine cards. Potassium and calcium are then added below sodium and magnesium (Figure 2). Students and teachers should note that the next 10 elements (scandium through zinc) do not behave as we would expect. A place should be opened up in the cards for these 10 elements as part of period four (Figure 3).

Mendeleev noted that arsenic did not behave like aluminum but instead like phosphorus. Therefore, Mendeleev made a bold move—he placed arsenic below phosphorus, leaving two empty spaces below aluminum and silicon (see the diagonal shading in Figure 3). Still defending his work in 1870, he predicted that the missing elements existed. He named his unknown elements "*eka*-aluminum" and "*eka*-silicon." According to Mendeleev, *eka* means *one* in Sanskrit and he said he used it to mean *resemblance to* (Posin 1948). Not until 1875, when gallium was discovered, was Mendeleev's work verified. Teachers should stress to students that concepts in science are often tentative, and it often takes years for ideas to be accepted.

Students complete the construction of their table by adding the rubidium-to-tellurium cards below potassium-to-bromine. By this point, students should understand the idea that elements are grouped together in families that share similar properties. Because iodine has properties similar to those of bromine, and tellurium has properties like those of selenium, the correct positions of these elements are the reverse of what is expected based on their atomic masses—one of Mendeleev's remarkable insights. Mendeleev switched tellurium and iodine to put them in the groups where their properties fit in better.

FIGURE 3

Transition elements and space for two yet-undiscovered elements (diagonal shading) were key features of Mendeleev's early table.

H 1.0																
Li 6.9	**Be** 9.0											**B** 10.8	**C** 12.0	**N** 14.0	**O** 16.0	**F** 19.0
Na 22.9	**Mg** 24.3											**Al** 26.9	**Si** 28.1	**P** 30.9	**S** 32.0	**Cl** 35.5
K 39.1	**Ca** 40.1	**Sc** 44.9	**Ti** 47.9	**V** 50.9	**Cr** 52.0	**Mn** 54.9	**Fe** 55.8	**Co** 59.0	**Ni** 59.0	**Cu** 63.6	**Zn** 65.4			**As** 74.9	**Se** 78.9	**Br** 79.9
Rb 85.4	**Sr** 87.6	**Y** 88.9	**Zr** 91.2	**Nb** 92.9	**Mo** 95.9	**Tc** 98	**Ru** 101.1	**Rh** 102.9	**Pd** 106.4	**Ag** 107.9	**Cd** 112.4	**In** 114.8	**Sn** 118.7	**Sb** 121.8	**Te** 127.6	**I** 126.9

FIGURE 4

The periodic table based on Mendeleev's 1869 version.

	Gruppe I.	Gruppe II.	Gruppe III.	Gruppe IV.	Gruppe V.	Gruppe VI.	Gruppe VII.	Gruppe VIII.
Typische Elemente	H 1							
	Li 7	Be 9,4	Bo 11	C 12	N 14	O 16	F 19	
1. Periode Reihe 1	Na 23	Mg 24	Al 27,3	Si 28	P 31	S 32	Cl 35,5	
- 2	Ka 39	Ca 40	—44	Ti 50(?)	V 51	Cr 52	Mn 55	Fe56, Co59, Ni56, Cu [63
2. Periode Reihe 3	(Cu 63)	Zn 65	—68	—72	As 75	Se 78	Br 80	
- 4	Rb 85	Sr 87	(Yt 88)(?)	Zr 90	Nb 94	Mo 96	—100	Ru104, Rh104, Pl106, [Ag108
3. Periode Reihe 5	(Ag 108)	Cd 112	In 113	Sn 118	Sb 122	Te 125	J 127	
- 6	Cs 133	Ba 137	—137	Ce 138(?)	—	—	—	
4. Periode Reihe 7	—	—	—	—	—	—	—	
- 8	—	—	—	—	Ta 183	W 184	—	Os 199 (?), Jr 198, Pt [197, Au 197
5. Periode Reihe 9	(Au 197)	Hg 200	Tl 204	Pb 207	Bi 208	—	—	
- 10	—	—	—	Th 232	—	Ur 240	—	
Höchste salzbild. Oxyde	R^2O	R^2O^2 od. RO	R^2O^3	R^2O^4 o. RO^2	R^2O^5	R^2O^6 o. RO^3	R^2O^7	R^2O^8 od. RO^4
Höchste H-Verbindung				RH^4	RH^3	RH^2	RH	(R^2H) (?)

(Courtesy of Edgar Fahs Smith Memorial Collection, Department of Special Collections, University of Pennsylvania Library.)

Years later it was discovered that periodic trends in the elements actually depend on atomic number, not atomic mass, and this provides an opportunity to teach students that models in science are tentative and subject to change as new evidence is discovered. At the end of the summary the teacher should add hydrogen above lithium (see light shading in Figure 3) and also note that the noble gases are not included because they were not discovered at the time. Teachers can add historical authenticity by displaying Mendeleev's table on an overhead projector or by handing out a copy to each student. One version of his table is reproduced in Figure 4.

Teachers should stress throughout their summary of his work that Mendeleev relied on empirical evidence as he looked for patterns in the properties. His novel approach to the problem of periodicity required imagination and creativity. Also, although he worked alone, Mendeleev acquired much of his evidence from other scientists. When he completed his table, he published his results for review by other scientists. All of these aspects are essential parts of the nature of science. Teachers can add even more interest to the summary by showing videos of the chemical reactions of some elements at appropriate times, available on commercial programs, and also on the Internet.

This method of concept development might also be used for topics such as the Copernican revolution, Newtonian mechanics, atomic theory, biological evolution, germ theory, and molecular biology. (A suggested bibliography on many of these topics appears with the online version of this article at *www.nsta.org/highschool#journal.*)

The aspirin inquiry

Engaging in laboratory work is an excellent way for students to learn how science functions. They might also learn that "pursuing science as a career or as a hobby can be both fascinating and intellectually rewarding" (NRC 1996, 200). The following activity can be used not only to teach laboratory skills and science content but also to show students the kinds of jobs that involve chemistry. Chemical technicians conduct the kind of testing used in this lab, and some students might be interested in exploring the field.

The following activity adds a historical dimension to lab work by looking at the development of aspirin, which in the early 1900s was in its infancy as a widely used pain reliever. Largely unregulated, so-called patent medicines were often counterfeited and sold as the real thing. The Food and Drug Act of 1906 allowed the Bureau of Chemistry (forerunner of the FDA) to prosecute

such counterfeiting, but many adulterated medicines still made it to consumers. This activity can be used to remind students "science is not separate from society but rather science is a part of society" (NRC 1996, 201).

Aspirin lab

To begin the activity, students are asked how they know that medicines are what they claim to be. Although the activity is based on events in the early 1900s, the question is still relevant as we debate the safety of pharmaceuticals imported from other countries. Students are then told that this investigation shows how to test for aspirin.

Students should read the brief history of fraudulent aspirin in the early 1900s (Figure 5). Teachers then arrange students in lab groups and tell them they are government scientists in post–World War I America, trying to distinguish fake aspirin from real aspirin. When they complete their work, students write a report on their findings to be sent to the Federal Bureau of Chemistry.

Each group of students will need a 100 mL plastic drinking cup to hold each substance to be tested: enteric coated brand name aspirin, uncoated brand name aspirin, enteric coated generic aspirin, uncoated generic aspirin, children's orange chewable aspirin, cornstarch, and salicylic acid. Each lab group will also need a small disposable pipette and a supply of approximately 0.1 M iron (III) chloride solution ($FeCl_3$). Students add 2–3 mL of $FeCl_3$ to each cup holding different "pain relievers" to be tested and observe the results (see Figure 6 for expected results). Students must wear protective eyewear during the activity and wash their hands after the activity.

CAUTION

When the golden brown $FeCl_3$ solution is dispensed from a pipette onto white salicylic acid, a dark purple color will immediately appear. Aspirin (ASA) will not immediately produce a dramatic color change. However, ASA, which is not very soluble in water, will slowly react with water to produce salicylic acid and as a result of the slow hydrolysis reaction, a pale purple color slowly appears. After discussing the results with the class, teachers can give each group of students an unknown to test. Then students can write reports. This is part of a longer lab activity that investigates fake aspirin products. It is similar to many "unknown powders" activities. The complete activity along with background chemistry and an extensive history of aspirin can be accessed at *www.chemheritage.org/EducationalServices/pharm/asp/asp00.htm*.

Student research and presentations

Like practicing scientists, students need to develop research skills, not only for academic class work but also to

FIGURE 5

Historical context for fake aspirin products.

The History File

Aspirin: Real or phony?

Bayer Company, the German chemical giant, had the great good fortune to get out of the dye-making business and into the pharmaceuticals business very early. Bayer called its first pharmaceutical product, created from waste products, *acetophenetidin*. Hoping to promote this pain reliever under its brand name rather than its chemical or generic name, its creators called this new drug Phenacetin. This new pharmaceutical marked the beginning of the modern drug industry—for the first time, a drug had been conceived, developed, tested, and marketed by a private company. Bayer looked forward to enormous profits from this and future drug products it might create.

In ancient times it had been discovered that the salicylic acid (SA) from white willow bark had analgesic and anti-inflammatory properties. SA was pretty hard on the digestive system, however, so a more gentle form was sought. Bayer, in the person of Felix Hoffmann in 1897 succeeded in producing that compound, acetylsalicylic acid (ASA).

In 1903, Bayer opened a large aspirin plant in Rensselaer, New York. Holding the U.S. patent on aspirin, Bayer was well-positioned to capture a large portion of American market for aspirin. But Bayer could not foresee World War I and the seizure of its U.S. assets by the U.S. government to be sold at auction to Sterling Drug Company.

Even before the breakup of Bayer, contraband formulators and smugglers had been making sure that cheaper, and illegal, bogus aspirin products made it to drugstore shelves. Many of these illegal aspirin products were simply cornstarch, or some aspirin mixed with cornstarch or any other white, powdery substance that was cheap. It was left to the U.S. government to discover the difference between real aspirin and the fakes.

FIGURE 6

Anticipated results for "Aspirin: Real or phony?"

Cut tablet	Appearance of cut tablet	Appearance immediately after addition of $FeCl_3$	Appearance after 30 minutes
brand name aspirin (coated)	white crumbly tablet with orange coating	slight purple color appears	no change since last observation
brand name aspirin (uncoated)	white crumbly tablet	no change since last observation	slight purple color appears
generic aspirin (coated)	white crumbly tablet with orange coating	slight purple color appears	no change since last observation
generic aspirin (uncoated)	white crumbly tablet	no change since last observation	slight purple color appears
children's chewable aspirin	orange crumbly tablet	no change since last observation	slight purple color appears
cornstarch	white powder	no change since last observation	no change since last observation
salicylic acid	white powder	deep purple color appears	no change since last observation

become lifelong learners. By examining the life and work of scientists, students can learn science content, develop understandings about inquiry, and see the relationship between science and society. If students can connect the story of one scientist to other stories, they begin to understand that science has evolved over time and that science is connected to ideas and events inside and outside the field of science. Student research is also an opportunity to engage students in interdisciplinary studies.

Students, individually or in teams, can be assigned biographies of famous scientists or scientific discoveries. Teachers can assign and organize scientists in support of the content covered in class. For example, the "science giants" may be the focus, or maybe some scientists who are currently active in a particular field (students can be encouraged to write or e-mail them!). Scientists can be grouped in clusters, with all of the gas law chemists in one grouping. Scientists can also be organized by time period, country, or origin.

Teachers can address the multicultural nature of the scientific endeavor by including biographies of minority and female scientists like Alice Hamilton (early champion of public health and occupational safety), Mario Molina (Mexican-born 1995 Nobel Prize recipient in Chemistry for his work on ozone and CFCs), Lise Meitner (pioneer in nuclear fission), or Percy Julian (African-American chemist best known for synthesizing a substance to treat glaucoma). Teachers can also focus on local state or regional science and scientists. The product of this type of assignment is often a written paper, but teachers can require posters, videos, or electronic presentations in place of, or in addition to, papers.

Evaluation will require a rubric for students to understand what needs to be included. Teachers can require in-depth learning by adding a few creative features. For example, having students create "documents" related to the scientist's life—such as a birth certificate, pages from their journal, a resume, news articles, or personal correspondence—requires students to understand the scientist's life and work. If the scientist's work involved scientific instruments, students might be asked to create models of them, for example. When all the assignments are turned in, students should identify the scientists who share commonalities; this can lead to a discussion about the history of science.

Our experiences show that using strategies appropriate to the science content being taught allows teachers to include the history of science in classes without sacrificing time or content. By adding historical context to any course concepts, instructors can teach a wide range of ideas related to inquiry and the nature of science. Teachers can present role models to a wide variety of students. And by telling the stories of scientists and their discoveries, teachers can motivate students to greater interest and participation in science. ■

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References

National Research Council (NRC). 1996. *National Science Education Standards*. Washington, D.C.: National Academy Press.

Posin, D.Q. 1948. *Mendeleev, The Story of a Great Chemist*. New York: McGraw-Hill.

Texley, J., and A. Wild, eds. 1996. *Pathways to the Science Standards, High School Edition*. Arlington, Va.: National Science Teachers Association.