Chapter 2

Why Chemistry?

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Isn't it obvious? Could guidance for implementation of a document called *National Science Education Standards* (NSES) be written without a discussion of chemistry and all of the other disciplines based on chemistry and chemical principles? After all, chemistry is a fundamental science. The goal of the standards is to ensure that all children and eventually all citizens are scientifically literate. Surely, chemistry must be integral to scientific literacy.

Maybe it's not so obvious. In the context of this time in history, chemistry has been identified with odors, explosions, poison, war, and cancer. The teaching and practice of laboratory work has become increasingly expensive and difficult to conduct safely and competently. Could a student become sufficiently scientifically literate by studying and understanding biology, physics, earth science, and meteorology? Perhaps chemistry might be an unaffordable luxury.

So for a moment, as chemists and teachers of chemistry, let us suspend our disbelief at that last statement and carefully consider the case for chemistry.

Chemistry fits neatly between the largely macro world of biology and the largely micro world of fundamental physics, and, in a sense, they both depend upon chemistry. Biological processes of cellular operations and organism reproduction are driven by chemistry. Exploration of physics would be impossible without man-made materials, such as advanced materials of particle accelerator construction and NASA's Gravity Probe B—and the chemistry that produces them.

In 2005, the American Chemical Society devoted the year to identification of a new vision for the Society. Thousands of member opinions were solicited and digested, which eventually led to the following: "Improving people's lives through the transforming power of chemistry." Why chemistry?

Table 1. Better Things for Better Lives

Chemistry is an academic exercise but brings its greatest value when applied to human need. Chemists create medicines that cure and manage diseases and allow longer, happier, and more productive lives. They create the materials—plastics, semiconductors, alloys, composites—that keep food fresh and safe, enable our computer-driven society, eliminate corrosion, and make vehicles stronger, lighter, and safer.

Chemical inventions range from medical necessities to everyday products that make life easier. The National Historic Chemical Landmarks program, administered by the American Chemical Society, celebrates many of these inventions.

Selman Waksman and Antibiotics. Waksman and his students, in their laboratory at Rutgers University, established the first screening protocols to detect antimicrobial agents produced by microorganisms. This deliberate search for chemotherapeutic agents contrasts with the discovery of penicillin, which came through a chance observation by Alexander Fleming. During the 1940s, Waksman and his students isolated more than 15 antibiotics, the most famous of which was streptomycin, the first effective treatment for tuberculosis.

Nylon Changes Fabric of Life. DuPont introduced nylon, the first synthetic fiber, in 1939 to compete with cotton, silk, wool, and rayon. The new product forever changed the textile industry and gave women's hosiery the name by which they are still known: nylons.

Do-it-Yourself Movement Born in Paint. The Sherwin-Williams Company developed Kem-Tone when the winds of World War II reduced the supply of petroleum, linseed oil, and other traditional paint ingredients. Company chemists were asked to create a durable paint that could be made with readily available substances, such as water. They looked to the ancient Egyptians for ideas and discovered that casein (a milk protein) mixed with varnish, water, and other ingredients produced a paint that covered in one coat and kept its color even with repeated washings.

The Columbia Dry Cell Battery. In 1896, the National Carbon Company (predecessor of Energizer) introduced the sealed, six-inch, 1.5-volt Columbia dry cell, the first battery marketed for consumer use. The technology of the Columbia, a carbon-zinc battery using an acidic electrolyte, served as the basis for all dry cell batteries for the next 60 years, until the introduction of the alkaline battery by the Eveready Battery Company (now Energizer) in the late 1950s.

The Development of Tide. Tide, the first heavy-duty synthetic detergent, debuted in 1946, the culmination of a search to replace traditional soaps, which did not clean well in hard water, where they deposited a residue of scum, or curds. Tide was not just a new product, but a new kind of product. It was based on synthetic compounds rather than natural products. Although initially targeted for marketing in areas of hard water, synthetic detergents—with Tide in the lead —soon displaced traditional soaps throughout the United States.

Of the basic sciences, chemistry is the one that most directly translates to products that people use and that can have a direct impact on their lives. Chemistry fuels an industry that reduces its inventions directly to practice. Table 1 summarizes several such transfers of innovation into practice. But most importantly, chemistry fits neatly with the case made for scientific literacy in the introduction to the NSES. To paraphrase: (1) Science literacy fosters personal fulfillment and excitement; (2) modern life requires scientific ways of thinking; and (3) scientifically engaged citizens will help society address shared responsibility and fairly manage shared resources. By substituting "chemistry" for "science," this chapter will examine these three goals in a chemistry context.

Chemistry literacy fosters personal fulfillment and excitement

"Some people will want to be chemists and find cures or invent new things."

—Lindsay, age 15 *

Personal fulfillment comes in both material and spiritual ways. Materially, well over a million people are employed by or directly dependent upon the chemistry enterprise—industry, academe, and government—in the United States. While many people think of careers in chemistry as research based, and of course, many are, there are also many careers besides research.

The chemical industry operates safely, effectively, and efficiently because of process development, oversight, and maintenance by chemical engineers. Chemists in government conduct research, but also develop and implement regulations and policy that foster continuous improvement and protection of the environment. Chemical analysis is fundamental to a number of industries and government agencies.

In fact, the 21st century is the era of the "nontraditional" career in chemistry. Lisa Balbes (2007) has described chemists who have careers in information science, patent law, sales, marketing, business development, and even in public policy.

As a profession, chemistry remains economically desirable. Chemists experience similar rates of unemployment as other holders of equivalent college postsecondary degrees, but chemists' salaries greatly exceed the average for each degree level (Table 2).

Additionally, undergraduate chemistry is a part of the curriculum leading to undergraduate degrees in most other technical professions. For example, undergraduate premedicine education requires an understanding of acid and base chemistry, the organic chemistry of pharmaceuticals, the creation and use of new polymers, and the biochemistry of human systems. Similar knowledge is also required for careers in dentistry, pharmacy, and nursing.

***Sherman polled a high school class for reasons to study chemistry. A few of the responses are reproduced in this chapter.**

Table 2. Salary and Unemployment Data: Chemistry vs. All United States, 2005 (Heylin, 2006; U.S. Bureau of Labor Statistics, 2007)

	Chemistry		All United States	
Degree	Unemployment, %	Median salary, $M/year	Unemployment, %	Median salary, $K/year
Bachelor's	3.2	65.2	2.6	48.7
Master's	2.9	77.5	2.1	58.7
Doctorate	2.9	95.0	1.1	73.9

Chemistry has long been known as the central science because of its place in connecting and explaining the "how" of the other sciences. The interdependent nature of the sciences, as acknowledged in the NSES, indicates that chemistry is also critical to careers in biology, physics, geology, and agriculture, among others. Architects, engineers, and artists require an understanding of the nature of the materials they use. Cosmetologists use the chemistry of hair and makeup to obtain the best results for their clients. Firefighters, and especially fire officers, must understand the complex nature of combustion and must be ready to adapt fire suppression materials and fireground strategy accordingly. Elementary school teachers need chemistry to teach their students about the wonders of science and to answer the pesky question, "Why?"

Chemistry literacy fosters personal fulfillment and excitement. Ultimately, personal fulfillment is more spiritual and more important. Stories about high school teachers who inspired students to pursue the study of chemistry by the wonder of a chemical transformation or of chemists who dedicated their lives to the solution of a research problem solely for personal satisfaction are too numerous to ignore.

These stories include the personal stories of the authors. Sherman has shared her passion for chemistry which, in turn, ignited that same passion in some of her students. Her enthusiasm helped others not so interested in the class "to stick with it." Carroll was drawn to chemistry because of his high school chemistry experience. Most people are drawn to a career in chemistry because they love it. Chemistry satisfies their intellectual curiosity, their need to discover, to organize, to solve problems, and to understand the world around them, as can be seen in Table 1. Chemistry satisfies their need to create and to contribute to human well-being and opens the doors to other endeavors. Chemistry is fulfilling.

Modern life requires chemical ways of thinking

"You should study chemistry because it makes you smarter."
—Josh, age 16

The NSES document is clear. Standards exist to bring national consistency to education, an inherently local enterprise in the United States. The goals of the NSES are to define a "scientifically literate society," particularly where citizens "use appropriate scientific processes and principles in making personal decisions" and "engage intelligently in public discourse and debate about matters of scientific and technological concern."

Chemistry classes provide a learning platform for students to develop skills in technical writing, technical reading, data analysis, calculation, analytical thought, and working in teams—skills basic to daily life and successful employment. While not every job requires all of these skills and not every living moment requires technical analysis, our society and economy, if it is to be sustained, require people to exhibit a command of at least some of these attributes on a daily basis.

In a chemistry class, students are taught practical mathematics skills, and they learn how to find patterns in real data. Chemistry teaches the use of practical algebra skills in a setting beyond a mathematics class. Chemistry supersedes the basic algebra used to solve formulas and, like story problems, teaches students how to select the right formula for a situation.

Chemistry teaches students how to use proportions via dimensional analysis to make things larger or smaller in scale. This skill is useful in work beyond the chemistry classroom. Architects, engineers, and carpenters use proportions to make models and to design and build structures. Even in ordinary life, recipes must be doubled or cut in half depending on how many people the cook is feeding. Chemistry teaches the use of practical algebra skills that go beyond the conceptual framework of a mathematics class. Chemistry makes mathematics make sense.

Technical writing skills include logically arguing and supporting ideas, describing people and conditions, formulating cogent directions, and using clear, concise language. Technical reading skills include understanding text and extracting specific information, reading and following directions, using charts, pictures, and diagrams as sources of information, and recognizing and ignoring irrelevant material. These skills are sometimes taught in high school English classes but are heavily emphasized in chemistry.

Chemistry textbooks are designed to present information in a variety of formats. A functionally literate adult must be able to read and extract information presented in diverse forms; a chemistry textbook presents information from just such a variety of sources and provides students the opportunity to learn this skill.

Laboratories—even the "cookbook chemistry" kind—provide opportunities for students to read, follow instructions, and record observations. While central to laboratory reports, clear, concise writing, supported by data, is also critical to any persuasive argument in business or law.

Data analysis skills include reading and interpreting tables, charts, and graphs, fitting data into the "big picture," predicting future events, and generating new information. Data interpretation, in the context of chemistry, requires pattern recognition, and an understanding of support, contradiction, and anomaly. This requirement is not so far removed from analyzing data in personal medical histories, deciding which car is the best for the money, or making decisions about personal investments. In chemistry, students spend much time analyzing data and interpreting the data through simple question-and-answer strategies. The goal in the class, as in life, is to make supported generalizations based on scientific concepts and to apply those concepts to new situations.

While "physics" or any other sciences could be substituted for the word "chemistry" in the preceding paragraphs, chemistry is unique in its ability to address how issues of science and technology affect people individually and globally. These issues are important to policy, and policy ultimately impacts every citizen's life. Should corn be fermented and distilled to make fuel or reserved for food? Should nuclear power replace combustion of fossil fuels for electricity? How should garbage be recycled for the best benefit to the community? Should meat be irradiated to prevent the spread of disease? How will we deal with emerging epidemics or obsolescence of common antibiotics?

Citizens do not have to develop technical answers to these questions. Sometimes, the depth of the technical arguments is even beyond the specific expertise of scientists outside a field. However, citizens must be able to understand the basic arguments of the debate of food vs. fuel; greenhouse gases vs. nuclear waste reprocessing and storage; overall safe food handling practices; and national research and emergency response priorities. Without a basic knowledge of chemistry and the other sciences, taught in the context of its application to modern life, this debate becomes opaque or oversimplified to the level of bumper sticker slogans.

Chemically engaged citizens will help society address shared responsibility and fairly manage shared resources

"We should study chemistry because it allows us to really understand about the makeup and 'how come' of everything around us."

—Ashley, age 15

Most importantly, we study and practice chemistry to improve life in the aggregate for us all. Ten years ago, Stuart Hart (1997) revisited work of Paul Ehrlich and Barry Commoner, relating the sources of environmental burden in an equation:

Environmental Burden = f(population, affluence, technology)

How should society address the potential or reality of increasing environmental burden? Population cannot realistically be reduced in a socially acceptable way in the short term; in fact, most demographers believe that population will increase by about 50% before leveling off in the mid-21st century (Lutz et al., 2001).

Reduction in the overall level of affluence is unacceptable, at least politically, in the more affluent countries, and may have environmental consequences: poorer economies tend to be more environmentally destructive.

In short, Hart argues, humankind will not save its way into a high standard of living and a global economy that the planet can support indefinitely. The only answer that acknowledges and possibly accommodates growing population and growing affluence is technology. But the bar is set high: easy calculation suggests that we must extract a factor of 4 to a factor of 20 times more benefit from the dwindling or more costly resources we have in exchange for the same environmental burden. That need for technology advance largely falls on chemistry.


David Armer, USNCO

Few issues loom larger for the next half-century than energy. The late Nobel Laureate Rick Smalley outlined the case in a famous lecture, "Be a Scientist—Save the World" (Smalley, 2007). He argued for the critical need for new modes of energy generation and the pivotal role that nanotechnology will play in energy efficiency. In a similar presentation, Nathan Lewis (2007) of Caltech outlines the grand challenges for science and technology in this context, including "disruptive" solar technologies, more efficient electrochemistry, conversion of CO_2 to methanol and other liquid fuels, and other storage technologies. Chemistry is critical to each of these potential solutions.

Chemists design processes through principles of Green Chemistry and Engineering that reduce resource use and impact on the environment while still fostering economic growth. Many pharmaceutical chemical processes are characterized by waste intensity; the ratio of waste generation to production is 25 to 100 (Cue, 2005). Chemists use the principles of green chemistry to devise new, more efficient processes that decrease cost and reduce production of waste.

The road to cleaner, more abundant energy, better pharmaceuticals, lower-waste processes, and advanced materials—the kind of technology required to impact Environmental Burden—goes through chemistry. Bringing chemistry to bear on environmental burden is the only practical way to approach sustainability.

Why Chemistry?

"Every person should study chemistry, at least briefly."

—Steven, age 15

There is a consensus in the United States today that education is critical for economic prosperity. The NSES document asserts that "Science is for all students." Why Chemistry? If we wish to invest our students with grounding in science and an understanding of the way the world works in the hope that it will make them better citizens of the 21st century, grounding in chemistry and its impact on our lives are a critical part of that understanding.

Recommended Readings

Cobb, C.; Fetterolf, M. L. *The Joy of Chemistry: The Amazing Science of Familiar Things*. Promethius Books: Amherst, NY, 2005.

Emsley, J. *Molecules at an Exhibition: The Science of Everyday Life*. Oxford University Press: New York, 1998.

Sacks, O. *Uncle Tungsten: Memories of a Chemical Boyhood*. Random House: New York, 2001.

Schwarz, J. H. *Radar, Hula Hoops, and Playful Pigs: 67 Digestible Commentaries on the Fascinating Chemistry of Everyday Life*. ECW Press: Toronto, Canada. 2001.

Recommended Web Sites

Brain, M. How Stuff Works. http://howstuffworks.com (accessed March 24, 2008).

Davies, S. Suite 101: Chemistry. http://chemistry.suite101.com (accessed March 24, 2008).

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Cue, B. W., Jr. A New Game Plan. *Chem. Eng. News* 2005, *83*, 46–47.

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Lewis, N. Global Energy Perspective (Presentation), 2007. http://nsl.caltech.edu/energy.html (accessed April 10, 2008).

Lutz, W; Sanderson, W.; Scherbov, S. The End of World Population Growth. *Nature* 2001, *412*, 543–545.

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U.S. Bureau of Labor Statistics. Education Pays. http://www.bls.gov/emp/emptab7.htm (accessed April 10, 2008).