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ABSTRACT

This book is designed to assist teachers at the 9-12 grade levels in addressing the goals of the National Science Education Standards (NSES) in their own classrooms concerning the teaching and learning of chemistry. The Standards expect students to learn science in an active manner and emphasizes methods of inquiry and deductive reasoning based on qualitative observations and quantitative data. The expectation is that science for all students should promote both excellence and equity and involve hands-on as well as minds-on experiences. (KHR)

Chemistry in the National Science Education Standards

A Reader and Resource Manual for High School Teachers

American Chemical Society
Education Division
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Washington, DC 20036

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Introduction

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The National Science Education Standards (NSES), developed under the aegis of the National Research Council, are in the words of Bruce Alberts, president of the National Academy of Sciences, and Richard Klausner, chairman of the National Committee on Science Education Standards and Assessment—a "call to action." They are a battle cry to all those who are concerned about science education: parents, educational administrators, scientists, the business community, and especially teachers. The message is that new ways of teaching and learning science are at hand; it is in everyone's best interest that we succeed in changing science education to meet the needs of our citizens for the twenty- first century. The NSES provide a way to reach the national goal of science literacy for all.

The NSES were released at a time of intense interest and action focused on learning and teaching. They build on several other notable studies and reports published over the past several years, yet they differ in that the major emphasis is on goals for student learning rather than on specific course content. The standards emphasize "a new way of teaching and learning." They stress ultimate learning goals rather than define one specific route to achieving these goals.

This is not to suggest that the standards do not provide content and pedagogical direction. In fact, they take the very bold approach of expecting students to learn science in an active manner, patterned on the way that scientists do science. The emphasis is on methods of inquiry and deductive reasoning based on qualitative observations and quantitative data. The expectation is that science for all students should promote both excellence and equity and involve "hands-on" as well as "minds-on" experiences.

Continuing its long-standing leadership role in promoting science education at all levels, the American Chemical Society (ACS), through its Society Committee on Education (SOCED), was an active participant in the development of the NSES. The ACS now takes the next step by providing this document, which is designed to assist teachers at the 9-12 levels in addressing the learning goals of the NSES in their own classrooms.

In the spirit of the NSES, this manual is not prescriptive. Rather, its many authors put the standards into perspective by providing their personal views of what the standards imply for high school chemistry instruction and how the standards can be used to modify instruction in a variety of classroom situations.

The booklet begins with a broad commentary about the standards from Henry Heikkinen of the University of Northern Colorado, who was a major participant in their development, as well as the development of several other reform efforts. He outlines his views on what students need to know about science within the context of the NSES. Sylvia Ware of the ACS Education Division, who was also closely involved in the NSES development, looks at the role that chemistry plays in the standards.

Michael Tinnesand, also from the ACS Education Division, then clarifies the idea of unifying concepts that flow across the different science areas and thus exemplify the connections within and among the sciences. Diane Bunce of Catholic University considers the question of what we mean by inquiry learning, and Jerry Bell from the American Association for the Advancement of Science follows with a specific example of an inquiry lab based on the well-known "mystery powders." Michael Tinnesand, in a second contribution to this book, suggests approaches to developing lesson plans using the NSES, and Patricia Smith, formerly of the U.S. Air Force Academy High School, develops a model lesson plan on the topic of changes of state. Jerry Bell's second contribution brings forth ideas on how the chemistry of life systems can be used as an exciting and relevant route to learning chemistry. Then, Bonnie Brunkhorst from California State University at San Bernardino provides examples to bring an earth and space science context into the chemistry class. Ann Benbow from the ACS Education Division reminds us that not only are technology concepts included in the NSES, but also there are skills standards related to technology that need to be addressed when developing a "tech prep program."

Conrad Stanitski from the University of Central Arkansas uses environmental issues to bring chemistry and societal concerns to students, incorporating some of the *ChemCom* materials. Mary Virginia Orna of the College of New Rochelle helps us to see how historical events in science can bring the excitement of discovery to students while leading them to modern principles.

Kate Scantlebury from the University of Delaware explores the role of the mentor teacher who supervises the practicum of student teachers, given the new pedagogies promoted in the NSES. Dwaine and Lucy Eubanks from Clemson University consider the very important issue of assessment of student learning as addressed within the standards. Ronald Archer of the University of Massachusetts reminds us that many students will go far beyond the basic expectations of the NSES to a level equivalent to Advanced Placement, an option that is in no way discouraged by the NSES. Finally, Sylvia Ware moves us away from the classroom to discuss support for the classroom. She makes clear to administrators and politicians that reform requires resources and that these resources must include professional development opportunities for current and future teachers.

The standards are the cornerstone of our ongoing national efforts to improve the quality of science education for all our students. Their implementation will require a long-term effort and adequate support from educators, policy makers, and the broader public in order to accomplish the stated goals. Teachers will need support to continue their professional development and to be rewarded for effectively implementing reform efforts in their classrooms. Those at the college/university level who prepare our new teachers must change their approaches so as to model a range of effective pedagogies to promote student learning. Those who control curricula and resources must stimulate and promote a variety of strategies to meet the NSES goals. We really do not have any other acceptable choice!

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CHAPTER ONE

Thinking About Content Standards

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Two sets of comprehensive national guidelines now offer definitions of what all K-12 students should know, understand, and be able to do in all aspects of science, including, of course, chemistry. The National Science Education Standards (NSES)—produced under the aegis of the National Research Council (NRC, 1996) and the Benchmarks for Science Literacy, developed by Project 2061, American Association for the Advancement of Science (AAAS,1993)—have already influenced science education reform planning, policy, and action in many states and school districts.

The fundamental questions in chemistry education have remained unchanged since chemistry emerged as a secondary school course in the early 1800s. They focus on three areas of concern: learning, instruction, and assessment.

- What should students know and be able to do?
- How will they get there?
- How will we know whether they have?

Although the questions have not changed, the answers have, depending on what we know at a particular time about chemistry, learning, instruction, technology, and prevailing views about the purposes of schooling as well as economic and societal priorities.
Answers to these fundamental questions have been framed most recently in terms of standards and benchmarks. What should students know and be able to do? The NSES content standards and Project 2061 benchmarks provide answers expressed in terms of the fundamentals to be learned by every student. How will they get there? The NSES teaching standards and Project 2061 tools and blueprints offer criteria regarding effective instruction and curricula. In addition, NSES program and system standards spell out the external support needed to create and sustain standards-based science classrooms. How will we know whether they have? NSES assessment standards and Project 2061's assessment blueprint provide guidance on how to document student success in attaining standards-based goals and how such data can help inform and guide instruction.

Now that learning goals in science for all K-12 students have been established nationally (with related state and local efforts already accomplished or well under way), attention has turned to what standards imply for thinking, planning, and acting to improve science (and thus chemistry) teaching and learning. Many educators, parents, and community leaders are conscientiously trying to build their own understanding about implications of standards-based reforms.

Unfortunately, these meaning-building efforts, while clarifying the reform agenda still ahead of us, have generated several unfocused or misleading notions. Some of these misconceptions about standards-based science education are pervasive enough to justify attention here, since they have implications for how major ideas discussed later in this book may be received or interpreted.

Means vs. Ends
The ultimate goal of current chemistry education reforms is *not* to improve the quality of classroom instruction, develop better textbooks or teaching units, implement better laboratory activities, or administer more authentic student assessments. Nor is the goal to implement new instructional technologies, foster group work, or even use "hands-on/minds-on" strategies.

All of these approaches have considerable merit. However, their value lies in their respective contributions as *means* to a common, unitary, well-focused *end* or goal: improved student learning of the central facts, ideas, and skills of science. From the viewpoint of standards-based reform, the only "quality claim" that counts for any of these instructional ideas is that they clearly contribute to the goal of improved science learning by students. They are all means to an end, not ends in themselves.

Standards vs. Curricula
The following "means vs. ends" distinction can clarify the role and limitations of science content standards. Content standards have approximately the same relationship to a school's curriculum as nutritional standards have to a particular diet or cuisine. It is clear that nutritional standards can guide the design of various diets and can help us judge their quality, but they do not dictate or define any particular sequence of meals. Putting it plainly, we do not dine on nutritional standards, but rather on a variety of meals that help us attain the desired level of nutrients. Likewise, strictly speaking, we do not teach (or even implement) content standards, but rather we plan, implement, and deliver sequences of instruction (curricula) intended to help students attain those learning goals.

Diversity vs. Unity
Even though there is one set of agreed-upon nutritional standards, we find a wide variety of diets and cuisines across cultures and nations, most of which (at least in principle) can satisfy those standards. In fact, we seek out and prize variety and diversity in our meal choices. (How many individuals elect to consume their full daily allotment of dairy products within one meal?)
Similarly, content standards do not define or mandate any particular organization of science courses or the science curriculum. There are many pathways to the set of learning goals defined by content standards or benchmarks.

Where's the Chemistry?
It's true that the word chemistry does not appear in either the table of contents or index of the NSES or Benchmarks for Science Literacy. However, it may be reassuring to chemistry educators to note that neither does "biology," "physics," "geology," or "astronomy."

The absence of these nouns as organizers for science content standards or benchmarks is not a cause for alarm. It does not deprecate the historic importance of these branches of science or their utility as designators of current school science courses. Rather, it reminds us that these documents do not describe courses or curricula; they simply map the intended facts, ideas, and skills of science that all students—over their full K-12 experience—should know, understand, or be able to do.

However, it is reassuring that the central facts, ideas, and skills of chemistry are clearly mapped within the eight defined categories of NSES content standards: unifying concepts/processes in science, science as inquiry, physical science, life science, earth/space science, science and technology, science in personal/social perspectives, and history/nature of science. That simply acknowledges and reinforces chemistry's role as the "central science," with applications and implications across all branches of the natural sciences. (See also Chapter 2.)

NSES and Project 2061 benchmarks both emphasize that their presentations of valued learning goals within particularly named clusters does *not* imply anything about how school teaching units, courses, or curricula should be organized. Confusion on this point can be clarified, once again, by distinguishing means from ends: Just as specifying a journey's destination does not imply any particular route or mode of transportation, organizing and presenting learning "ends" are different from organizing the instructional "means" used to reach them.

Given that perspective, it is not surprising that standards and benchmarks do not address the desirability of either discipline-based or interdisciplinary/integrated approaches to curriculum design. However, the advent of content standards ensures that we can initiate cross-disciplinary discussions about the science curriculum without the threat of "watering down" or compromising valued chemistry learning for all students. Content standards ensure that *all* intended learning will remain on the curriculum design table.

Some vs. All
A commonly expressed teacher reaction to a review of the chemistry content in NSES or Project 2061 benchmarks is, "We already teach that." However, even though many secondary school chemistry courses include that content, two standards-based observations must be addressed: The content standards apply to *all* students, not just students who currently elect to study high school chemistry. *(All* means *every* student, not just some or even many students enrolled in current chemistry courses.) Even though the material is in fact taught to students, the more demanding standards-based expectation is that the specified content will be *learned* by all students. Both points have clear implications for how secondary school standards-based science courses should be organized and delivered and suggest that adopting content standards is only the first step in a much longer science education reform agenda.

Floors vs. Ceilings
Some observers have expressed concern that content standards will reduce the richness of students' current science (or chemistry) learning to a homogenized, lowest common denominator level. In other words, the thinking goes, students in a standards-based school system will not pursue studies in science or chemistry that exceed the level and scope defined by content standards. This worry is prompted by a confusion of floors for ceilings. Science content standards represent the basic level of science understanding and skills that *every* student should carry away from K-12 studies. Content standards express the minimal level of science learning expected by all students, a common floor for everyone. However, the "science for all" vision of standards does not in any way preclude or discourage additional science-learning opportunities, enrichment, and course options for students motivated and capable of pursuing them. Content standards define a science-learning floor, not a ceiling.

Standards vs. Content Standards
"Implementing standards" is sometimes taken to mean only that the K-12 science curriculum supports student learning defined by content standards. However, full implementation of the vision of NSES implies that five additional categories of standards are addressed: standards for science teaching, standards related to professional development for science teachers, standards for assessment in science education, standards for science education programs, and standards for science education systems.

All five of these additional "flavors" of standards are fully described in the NSES document and are also addressed by Project 2061 blueprints. Thus, even in states or districts where locally developed policies have focused on K-12 standards for science content, it remains important to consult these national documents. Helpful perspectives and support regarding the need for aligning all components of the educational system around explicit learning goals for students are found in those resources.

Inquiry vs. Content
Historically, chemistry teachers, and science teachers in general, have often debated whether classroom emphasis should be given to the development (if any) of inquiry skills or to the development of science content. The advent of science content standards has essentially undercut that debate. Inquiry is defined by NSES as one of eight categories of science content. As content, inquiry includes both understanding about scientific inquiry and the abilities needed for students to do inquiry.

Thus, both the "knowing about" and "doing" aspects of scientific inquiry are integral parts of what it means to teach standards-based science content. It is no longer inquiry vs. content in the teaching of chemistry; it is now inquiry *as* content.

Can vs. Should
One objection sometimes expressed about science content standards or benchmarks is that many current students cannot, in fact, master some or much of what is specified, particularly at the secondary school level. That objection is based on the assumption that standards are intended to map—and should be judged by—what all students are presently capable of knowing and doing.

By contrast, content standards and benchmarks represent national consensus regarding what all students *should* be capable of knowing and doing—a vision of what classroom instruction in science should develop in all students over the full K-12 program. Thus, for example, science content standards for grades 9-12 are based on the assumption that students have previously mastered all standards-based science expectations for grades K-4 and 5-8.

In that light, it is not surprising that many high school students today may not be able to master expectations defined in grades 9-12 science standards. NSES and Project 2061 benchmarks were published in 1996 and 1993, respectively. Even if standards-based reforms had been fully implemented upon their recent release, today's high school science students would possess few years of standards-based science background.

If standards-based science had been fully implemented in a school system in 1996, it would be 2007 before 11th-graders possessed the knowledge and skills of a full standards-based K-10 science program. The proposition advanced by the developers of standards and benchmarks is that such students will be capable of demonstrating much higher performance in all aspects of secondary school science; that is, the science education vision defined by standards can eventually be realized.

It should be clear, given the above discussion, that identifying and proclaiming what all K-12 students should know, understand, and do in chemistry is, comparatively speaking, the easiest part of the standards-based reform agenda. The remaining agenda includes the need to align the curriculum, instruction, and student assessments with those intended student learnings. Success in those efforts, in turn, depends on building clarity and shared interpretations of exactly what the adopted standards or benchmarks imply regarding the scope, level, and depth of student learning.

One way to explore the key challenges and tasks ahead is to reflect on what teachers and school administrators should "know, understand, and be able to do" about the implications of well-defined content standards, whether those standards focus on chemistry or other valued science content. That's what this book is all about!

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Henry W. Heikkinen is a professor of chemistry and the director of the Mathematics and Science Teaching Center at the University of Northern Colorado. He participated in the development of NSES, co-chaired the Colorado State Model Content Standards working group, serves as a consultant to AAAS Project 2061, and is a member of the College Board's Science Academic Advisory Committee.

CHAPTER TWO

Chemistry in the National Science Education Standards

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Some chemistry teachers, on reading the National Science Education Standards (NSES) for grades 9-12, have concluded that "there is not much chemistry in the standards" and that they are already teaching chemistry at a level that far exceeds the national standards. The first conclusion is inaccurate; the second is probably inaccurate as applied to the majority of chemistry teachers, given the content of the traditional introductory chemistry course and the ways in which this material is typically introduced to students.

One reason for this confusion is that, as Heikkinen clarified in Chapter 1, the word chemistry is not used to identify any particular segment of content in the standards. The fundamental science concepts and principles in the standards were selected to cover "the intellectual and cultural traditions that characterize the practice of contemporary science." Where we find chemistry content in the NSES depends on our definition of the intellectual territory of modern chemistry.

Former ACS president Ronald Breslow (1997) has described the territory of chemistry as follows:

> Chemistry is the science that tries to understand the properties of substances and the changes that substances undergo.It is concerned with substances that occur naturally—the minerals of the earth, the gases of the air, the water and salts of the seas, the chemicals found in living creatures—and also with new substances created by humans. It is concerned with natural changes—the burning of a tree that has been struck by lightning, the chemical changes that are central to life—and also with new transformations invented and created by chemists.

This view of chemistry obviously covers a more diverse intellectual territory than is conveyed by most introductory chemistry courses. Since so few students take more than introductory chemistry courses, the burden is on these courses to present an accurate and comprehensive view of our discipline. Chemistry is not only a physical science but also an earth science, a life science, an environmental science, a materials science, and—as Breslow illustrates most effectively in his book—"the central, useful, and creative science."

Those who are comfortable with this view of modern chemistry have no difficulty finding chemistry concepts and principles throughout the content standards (NRC, 1996):

- Physical Science (Content Standard B),
- Life Science (C),
- Earth and Space Science (D),
- Science and Technology (E),
- Science in Personal and Social Perspectives (F), and
- The History and Nature of Science (G).

If chemistry teachers are guided by the NSES, they will begin to broaden introductory courses to include examples from organic chemistry, biochemistry, industrial and environmental chemistry, geochemistry, and materials science. This will make the introductory knowledge base more reflective of the breadth of modern chemistry. Also, it will bring the content of introductory chemistry in the United States closer to the content of similar courses in other countries. There really is more than one way to introduce students to chemistry!

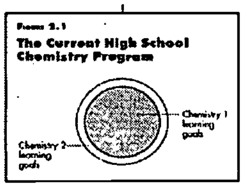
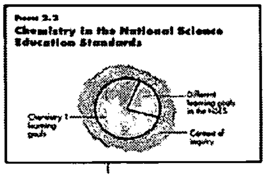


Figure 2.1
The Current High School Chemistry Program

As Heikkinen pointed out, the NSES include "inquiry" as one component of science content (Standard A). As defined in the NSES, inquiry-based instruction should permit students to develop a wide range of abilities and understandings related to the processes of scientific investigation. The inquiry standard does not prescribe a specific sequence of procedures to follow when investigating science (as in *the* scientific method); rather, the focus is on the asking of questions, the testing of ideas, and the logic of evidence. Science should not be taught as "received wisdom."

Inquiry-based instruction should be an integral component of all science courses to facilitate the students' understanding of science, its nature, and its methods. Of course, teaching in an inquiry mode requires great teaching skills and a lot of time.



Unfortunately, school systems will not allocate more time to chemistry just because we now are implementing standards-based instruction. Therefore, we cannot add new topics to introductory chemistry and take the time to teach in an inquiry mode, as defined in the NSES, unless some topics that are now included in the introductory course are dropped from the syllabus. Some teachers believe they are teaching beyond the national science content standards because they are teaching more inorganic and physical chemistry than is explicitly described in the content standards. If they are not also teaching some organic chemistry, biochemistry, and environmental and industrial chemistry and teaching in an inquiry mode, they have *not* covered the knowledge base of the content standards. They are not teaching toward the same goals. What is the relationship between the learning goals defined by the NSES and the learning goals found in traditional high school chemistry programs? Traditional courses tend to emphasize physical and inorganic chemistry and may not focus on inquiry or student-directed investigations. When compared to the NSES some of the familiar concepts and principles of Chemistry 1 and 2 are either taught from a different context (e.g., using examples from organic chemistry or materials science) or are dropped altogether. (Remember, this is the floor, not the ceiling.) The new learning goals include a strong emphasis on student understanding and skills related to inquiry.

ChemCom and the NSES

How does *ChemCom,* the ACS high school course (ACS, 2002), relate to this model and the science content standards? *ChemCom* corresponds closely to the fundamental concepts and principles listed in the NSES and goes beyond the level implied by the Chemistry standards. Inquiry based learning is an essential component of *ChemCom,* although some inquiry skills may not be as explicitly defined in the text as in the NSES.

As indicated previously, chemistry concepts and principles can be found throughout the different categories of content standards, not only in the section on physical science (Standard B). In the standards document, each standard is relatively brief. For example, Physical Science Standard B states

As a result of their activities in grades 9-12, all students should develop an understanding of

- structure of atoms,
- structure and properties of matter,
- chemical reactions,
- motions and forces,
- conservation of energy and increase in disorder, and
- interactions of matter and energy.

The explanation within the NSES makes clear that the six sections of Standard B cover concepts and principles usually taught in physics as well as chemistry. Thus, it is not to be expected that all the sections of this particular standard would be fully addressed by either a chemistry or a physics course standing alone.

Life Science Standard C is also divided into six sections. While mainly focusing on the intellectual domain of the biological sciences, it also includes important chemistry principles that may be assumed, but not taught, in Biology 1 classes. Similarly, Earth and Space Science Content Standard D includes chemistry in each of its four sections, although the concepts and principles listed go beyond the range of a chemistry class.

Each standard is accompanied by a section on "Developing Student Understanding" and a "Guide to the Content Standard." It is this guide that describes the fundamental concepts and principles that underlie each component of each standard.

CHEMCOM and the NATIONAL SCIENCE EDUCATION CONTENT STANDARDS

The National Science Education Content Standards (NSES) outline what all students need to know, understand and be able to do to be scientifically literate. No one course is sufficient to allow students to meet all the standards. In fact, meeting the standards should be the result of the total school experience of students. As a textbook for a first year chemistry course, we believe *ChemCom* provides excellent coverage of not only the physical science standards, but parts of all the other content standards as well.

In the Standards document, for clarity of intent, each standard is accompanied by a "Guide to the Content Standard" section. It is this guide that describes the fundamental concepts and principles that underlie each standard. The relationship of *ChemCom* to these underlying concepts and principles is addressed in the following set of tables. For any component of each of the seven content standards, *ChemCom* may:

- Address <u>all</u> of the concepts and principles in the guide.
- Address <u>most</u> of the concepts and principles in the guide.
- Address <u>some</u> of the concepts and principles, or
- <u>not</u> address the concepts and principles.

The (NSES) Life Science Standard C, while mainly focusing on the intellectual domain of the biological sciences, also includes important chemistry concepts that may not be taught in Biology I classes. Similarly, the Earth and Space Science Standard also includes chemistry concepts. In fact, modern chemistry is addressed throughout the seven content standards listed above, a reflection of the central and useful character of chemical knowledge.

There is also a standard that addresses concepts and processes that provide a connection between and among different scientific disciplines. This Unifying Concepts and Process Standard states:

As a result of activities in grades K-12, all students should develop understanding abilities aligned with the following concepts and processes:

- *systems, order, and organization*
- *evidence, models, and explanation*
- *constancy, change, and measurement*
- *evolution and equilibrium*
- *form and function"*

We encourage *ChemCom* teachers to work with other science teachers in their school to ensure that these unifying concepts are addressed across the curricula. The *ChemCom* student text is rich with examples of these concepts as they apply to chemistry. One way to introduce these concepts might be to organize cross-disciplinary seminars that give students the opportunity to discuss each of these unifying concepts in the context of the particular sciences they are studying. We encourage you to consult the National Science Education Standards for additional information on these unifying concepts and processes.

***ChemCom* AND THE NSES STANDARDS**

Standards (grades 9-12)	**Components**					
A. Inquiry	1	2				
B. Physical science	1	2	3	4	5	6
C. Life science	1	2	3	4	5	6
D. Earth and space science	1	2	3	4		
E. Science and technology	1	2				
F. Personal and social perspectives	1	2	3	4	5	6
G. History and nature	1	2	3			

LEGEND

Addresses all fundamental concepts and principles in this section of "Guide"

Covers most fundamental concepts and principles.

Addresses some concepts and principles.

Section concepts not typically addressed in first-year chemistry *courses*

A: Inquiry Standard

COMPONENTS	*ChemCom* Level of Coverage	ACTIVITIES IN *ChemCom*	*ChemCom* *UNIT(s)*
1. Abilities necessary to do scientific inquiry	Addresses all concepts: includes investigations, use of technology and math, using logic and evidence, modifying explanations, recognizing alternatives, communicating and defending scientific arguments	Labs, demonstrations, modeling matter, decision-makers, math problems with graphs, word problems, library research, multi-media.	Throughout
2. Understandings about scientific inquiry	Addresses all concepts: includes use of math, logic, methods of scientists, purposes for research, development of science ideas	Labs, demonstrations, modeling matter, decision-makers, math problems with graphs, word problems, library research, multi-media	Throughout

B: Physical Science Standard

COMPONENTS	*ChemCom* Level of Coverage	ACTIVITIES IN *ChemCom*	*ChemCom* *UNIT(s)*
1. Structure of atoms	Addresses <u>all</u> concepts: includes atomic particles, fission & fusion, radioactive isotopes, radioactive series, nuclear pile. See also standards A, F, G.	Labs, demonstrations, modeling matter, decision-makers, math problems with graphs, word problems, library research, multi-media	Water, Materials, Atoms
2. Structure & properties of matter.	Addresses all concepts: includes periodic table & properties, ionic and covalent bonding, hydrogen bonding, physical & chemical properties, states of matter, organic structures, gas laws. See also standards A, F	Labs, demonstrations, modeling matter, decision-makers, graphs, word problems, library research, multi-media.	Water, Materials, Petroleum, Air, Food, Industry
3. Chemical reactions	Addresses <u>all</u> concepts: includes organic, redox, acid/base reactions; reaction rates; catalysis; consumer, industrial & environmental reactions; pH; moles; stoichiometry; enthalpy, activation energy. See also standards A, F	Labs, demonstrations, modeling matter, decision-makers, graphs, word problems, library research, multi-media.	Water, Resources, Petroleum, Air, Food, Industry
4. Motions & forces	Concepts not typically addressed in first-year chemistry		
5. Conversation of energy & increase in disorder	Addresses <u>all</u> concepts: includes energy transfer, kinetic & potential energy, heat as random motion	Labs, demonstration, decision-makers, math problems with graphs, word problems, library research, multi-media.	Petroleum, Atoms, Air, Industry
6. Interaction of energy & matter	Addresses <u>all</u> concepts related to radiation	Labs, decision-makers, word problems, multi-media	Air, Atoms

C: Life Science Standard

COMPONENTS	*ChemCom* Level of Coverage	ACTIVITIES IN *ChemCom*	*ChemCom* *UNIT(s)*
1. The cell	**Addresses some concepts: chemical reactions in cells, proteins, enzymes, and photosynthesis. See also standards A, B, D, F.**	Labs, decision-makers, math problems, word problems, library research	Food, Air, Petroleum
2. Molecular basis of heredity	Concepts not typically addressed in first-year chemistry		
3. Biological evolution	Concepts not typically addressed in first-year chemistry		
4. Interdependence of organisms	Addresses most concepts: carbon & nitrogen cycles. See also standards A, B, D, F	Graphs, decision-makers, word problems, and library research.	Food, Air, Industry
5. Matter energy & organization in living systems	Addresses <u>most</u> concepts: includes food for energy & growth, biomolecules, ATP, cycle of energy & matter through living and nonliving systems. See also standards A.	Labs, decision-makers, math problems, word problems, library research	Food, Air, Industry

	B, D, F		
6. Behavior of organisms	Concepts not typically addressed in first-year chemistry		

D: Earth and Space Science Standard

COMPONENTS	*ChemCom* Level of Coverage	ACTIVITIES IN *ChemCom*	*ChemCom* UNIT(s)
1. Energy in the earth system	Addresses some concepts: earth's energy balance, atmosphere & climate, greenhouse effect. See also standards A, B, C, F	Decision-makers, graphs, word problems, library research	Air
2. Geochemical cycles	Addresses most concepts: includes non renewable sources, conservation, carbon cycle. See also standards A, B, F	Labs, decision-makers graphs, word problems, library research	Materials, Air
3. Origin & evolution of earth & system	Addresses some concepts: radioactive isotopes for dating half-lives. See standards A and B.	Labs, math problems, word problems, decision-making library research	Nuclear
4. Origin & evolution of universe	Addresses some concepts: nuclear fusion reactions. See standard B	Word problems, library research	Nuclear

E: Science and Technology Standard

COMPONENTS	*ChemCom* Level of Coverage	ACTIVITIES IN *ChemCom*	*ChemCom* UNIT(s)
1. Abilities of technological design	Address most concepts: includes evaluation and redesign of existing technologies.	Decision-making, word problems, library research	Water, Materials, Petroleum, Atoms, Air, Industry
2. Understandings about science & technology	Addresses all concepts: chemical, petroleum, and nuclear technologies, nature of science and technology	Labs, word problems, library research	Resources, Petroleum, Nuclear, Industry

F: Science in personal and Social Perspectives Standard

COMPONENTS	*ChemCom* Level of Coverage	ACTIVITIES IN *ChemCom*	*ChemCom* UNIT(s)
1. Personal & community health	Addresses some concepts: personal choice, food, chemistry and health	Labs, decision-makers, word problems, library	Water, Food, Atoms
2. Population growth	Addresses some concepts: chemical, material and petroleum		
3. Natural resources	Addresses all concepts: includes	Labs, decision-makers, graphs,	Resources,

	renewable and non renewable resources, uses & distribution of resources, recycling	math problems, library research	Petroleum, Industry
4. Environmental quality	Addresses all concepts; includes air and water quality issues and pollution prevention, nuclear wastes	Labs, decision-makers, math problems with graphs, word problems, library research	Water, Resources, Air, Industry
5. Natural & human-induced hazards	Addresses some concepts: risk analysis, water purity and nuclear hazards.	Decision-makers, graphs, word problems library research	Nuclear, Air, Personal Chemistry.
6. Science & technology in local, national & global challenges	Addresses all concepts: science, technology, economics, politics & social factors, complexity of decision-making.	Labs, demonstrations, decision-makers, math with graphs, word problems, library research	Water Materials, Petroleum, Food, Air, Atoms, Industry
G: History and Nature of Science Standard			
COMPONENTS	*ChemCom* Level of Coverage	ACTIVITIES IN *ChemCom*	*ChemCom UNIT(s)*
1. Science as a human endeavor	Addresses most concepts: includes careers, interactions of scientists with society, work of scientists.	Decision-making, word problems, library research	Throughout
2. Nature of scientific knowledge	Addresses most concepts: but material tends to be less explicit than described in Standards.	Labs, decision-makers, math & word problems.	Throughout
3. Historical perspectives	Addresses most concepts: atomic theory, nuclear chemistry, some molecular biology, energy resources, some medical technology.	Labs, demonstrations, word problems, library research.	Materials, Petroleum, Atoms, Air , Industry

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CHAPTER THREE

The Unifying Concepts

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With the release of the National Science Education Standards (NSES), there was a significant move to identify connections between and among the traditional scientific disciplines. Most schools and most teachers presently organize their programs around teaching the content of biology, chemistry, physics, and (sometimes) earth science. It is not unusual for these individual classes to be taught by separate faculty members and for teachers of one discipline to have little or no idea what has been taught in the other courses. This lack of coordination and communication forestalls any kind of synergy among the various traditional teaching disciplines.

The NSES address these problems by making the first content standard relate to the unifying concepts and processes common to all science classes, from grades K through 12. The unifying concepts and processes were not divided into grade levels, as are the other content standards, specifically because the developers believed that these unifying themes should be addressed at each and every grade level. (NRC, 1996).

The Teaching Standards

Chemistry prides itself on being called "the central science," the link to a basic understanding of *all* the scientific disciplines. And yet all too often the chemistry curriculum presents a very narrowly defined range of chemical topics. A typical chemistry course focuses on inorganic chemistry with a small amount of analytical chemistry added. There may be some organic or biochemistry in a chapter or two at the end of the book, but they are rarely reached. The unifying concepts in the NSES present a key opportunity to look for connections between chemistry and the other scientific disciplines. The unifying concepts are

- systems, order, and organization;.
- evidence, models, and explanation; .
- constancy, change, and measurement; .
- evolution and equilibrium; and .
- form and function.

The standards make some substantial suggestions relative to the teaching of science and the kinds of lessons we should present. A summary of the changes they suggest to address the "big ideas" that stretch across the science disciplines is found in Table 3.1.

Teaching the Unifying Concepts and Processes in Chemistry

Each of the unifying concepts is supposed to be taught each year a student is in school. The idea is for students to gain a simple knowledge of the concepts in their early years, and then develop a deeper and richer understanding as they receive more and more instruction in subsequent courses. But, how accessible are the unifying concepts for coverage in a typical first-year high school chemistry r course? They appear to present a particularly ripe opportunity to reinforce the concepts in the context of chemical principles.

The concepts of systems, order, and organization offer many examples in chemistry. Chemists often define systems to isolate energy flow and thermodynamic interactions. Much of chemistry relates to the concept of order. Our discussions of entropy and the tendency to maximize disorder in chemical systems fit very well with this concept. The periodic table is one of the most powerful organizing tools in all of science and serves as a comprehensive illustration of how trends in physical and chemical characteristics can be organized into scientific schemes.

The second set of concepts includes evidence, models, and explanation. Since so much of chemistry cannot be directly observed, much of what we have constructed about how matter behaves has been derived from explanations of evidence, using various models to interpret the observed data. Chemists use models for many purposes; for example, to illustrate an unseen reality such as molecules.

Table 3.1

Changing Emphasis by Unifying Concepts

Less Emphasis on	More Emphasis on
Stand-alone courses with little relevance or communication between disciplines	Connections between and among traditional scientific disciplines
Dividing important concepts and processes to be presented piecemeal and then ignored	Continuity of instruction on concepts and processes that are fundamental and comprehensive
Presenting concepts in a single context with no connection to other appropriate applications	Making the unifying concepts useful and understandable by the people who will implement them
No coordinated plan to develop unifying concepts or themes	Presenting the unifying concepts in a developmentally appropriate manner in grades K-12

The concepts of constancy, change, and measurement can be illustrated by the modern atomic theory. An atom of copper is the same no matter where it comes from. It maintains its nature even if it becomes combined with other atoms to make a new compound. We can even demonstrate the reduction of a copper ore to show how we can restore the atoms of copper to their original state. Chemistry also quantifies change by defining the rate of chemical reactions and the periodic trends among elements. The lab-centered nature of most chemistry courses provides a great deal of opportunity to have students make and interpret a wide range of measurements, using a variety of instruments. We also discuss the nature of measurements when we talk about accuracy, precision, and significant digits.

Evolution is a series of changes and, although it is usually associated with biological processes involving the changes in living organisms, it can also describe the chemical evolution of the elements from the beginning of time. Chemical evolution is also demonstrated in the rock cycle. Chemical equilibrium generally receives considerable attention in most chemistry courses. The understanding students have of chemical equilibrium could be enhanced tremendously if students have an opportunity to learn how the term is used in other science classes. This helps the teacher identify any misconceptions students may harbor about the nature of chemical equilibrium.

Finally, there are numerous examples of form and function to be found in chemistry. The shape of molecules dictates their characteristics and their interactions with other molecules. This is particularly salient in organic and biochemistry. The interactions of enzymes and substrates, protein characteristics, and DNA and RNA can be used to show how molecular structure influences the functions of these molecules.

The Unifying Thread

In the best of worlds, we would layout a blueprint for the science education of each child. We would construct an intellectual "assembly line" and would carefully insert the information, concepts, and processes we want each child to learn in each grade level. Each step would build on the previous step, deepening and enriching the student's understanding. The unifying threads serve as a scaffold for holding the knowledge together—a logical and essential ingredient in the learning process.

Unfortunately, all too often the reality is quite different: One grade level does not build on the previous one, the curriculum is not coordinated, and teachers do not know what has gone on with the students in previous classes. The unifying concepts in the NSES provide a linking thread from grades K through 12. They also reinforce a very solid pedagogical practice. Concepts introduced to young students must be presented in a simplified, concrete fashion. As students become more sophisticated, concepts can be presented in greater complexity. For example, the concept of "family" grows from the personal—families of people—to families of animals, and to families of elements.

This process of identifying examples of a concept and pointing out the characteristics that make the examples relevant is a very powerful means of teaching. By developing the unifying concepts and processes at each grade level, students should gain an in-depth understanding by the time they graduate

An Integrated Approach

There are some real barriers to teaching with a unified approach. Most secondary science programs are divided into content specialties such as biology, chemistry, and physics. Many school districts have graduation requirements that specify the number of science courses to be taken but not which courses. It is possible for students to take all physics and no biology in some school systems. This makes it difficult to coordinate students' learning from one year to the next. Integrated courses, where all the content of science is blended together around central themes, often make coordination much easier. Sometimes, however, integrated courses have suffered by concentrating on breadth of knowledge to the exclusion of depth. (Note that one criticism of U.S. science curricula in the Third International Mathematics and Science Study is that many of our middle school courses are *too* broad (Beaton et al., 1996).)

Some schools are experimenting with block classes, combining an Algebra II course with a chemistry course. Other schools are creating career clusters and delivering all mathematics and science in an occupational context such as engineering or business. We need to continue to develop the links between science and the rest of the curriculum, looking for links to social studies, English, and other subjects.

Interestingly, the NSES unifying concepts could serve as an excellent starting place for choosing a common thread that could serve as the theme for a school-wide interdisciplinary approach. Consider the concept of "cycle." Although we may tend to think of cycles only in a scientific context, there are numerous other disciplines that have equally rich applications of this concept. If students were exposed to all of these various applications in the course of a school year, it would enrich their understanding of the concept. Social studies classes could discuss cycles in terms of periods of peace vs. war. Business classes could study economic cycles, biology could explore life cycles, technical education classes could study engine cycles, and so on.

Students could demonstrate their understanding of the "big ideas," whether across the sciences only or across all school subjects, at parent-teacher programs, school science (or knowledge) fairs, etc. Student mastery of the big ideas could also be assessed through the content of individual student portfolios.

Many of the unifying concepts could stand as school-wide themes. Consider the concepts of organization, systems, evolution, change, or evidence. All of these have fertile possibilities for explication in language arts, social studies, art, technical education, mathematics, or nearly any other school content area. To introduce unifying concepts across disciplines, students could also organize a cross-disciplinary seminar or poster session for their fellow students to give them an opportunity to exchange ideas and enhance their communication skills.

The idea of aligning and integrating the science curriculum has always been a difficult but desirable goal. After all, in the real world, scientists work across disciplinary boundaries and on interdisciplinary teams. The NSES make the task somewhat more explicit by specifying what those unifying concepts should be. Now, the difficult task of implementing interdisciplinary learning goals must be addressed in the classroom, on a school-by-school, system-by-system basis.

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CHAPTER FOUR

Inquiry Learning: What Is It and How Do You Do It?

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One expectation of the 1996 National Science Education Standards (NSES) is that science teachers will use and be able to plan inquiry-based science programs. Inquiry as an approach to learning is defined as "a set of interrelated processes by which scientists and students pose questions about the natural world and investigate phenomena" (NRC, 1996). This sounds reasonable; many teachers can agree to inquiry learning in principle, just as many can agree that students should apply the scientific method in science classes. Difficulties arise when we, as teachers, try to implement this approach. That is when we realize that we may not fully understand what inquiry teaching and learning actually are.

Inquiry Teaching

The NSES document lists fundamental student abilities for inquiry learning at grades 9-12 (NRC, 1996).

- Identify questions and concepts that guide scientific investigations.
- Design and conduct scientific investigations.
- Use technology and mathematics to improve investigations and communications.
- Formulate and revise scientific explanations and models using logic and evidence.
- Recognize and analyze alternative explanations.
- Communicate and defend a scientific argument.

The NSES also identify a series of fundamental understandings that students should acquire about scientific inquiry. These understandings relate to the purposes, methods, techniques, tools, results, and communication of results of scientific investigations.

Analysis of the expected student abilities and understandings leads to the conclusion that the standards are stressing the *how* and *why* of scientific phenomena. Students are being asked to do science themselves, not just read how the experts do (or, more often, did) it. In a lot of ways, the inquiry approach to science instruction is closer to science in the real world. It is less authoritative and formal. It is more "learner-friendly." By using this teaching approach, we are essentially telling students that they are capable of doing and learning science. They will learn that science is an activity for all humans–you do not need a master's degree or doctorate before you are permitted to study it–and that everyone can do science at some level. They will learn that science is a way of looking at the world and explaining it, a way that uses many tools, including logic, mathematics, and technology, to further its investigations. Most important, they will learn that the prime requirement for learning science is to be a person who asks why.

The NSES make clear that inquiry learning requires that students actively participate in scientific investigations. Furthermore, these investigations should be guided by concepts and be performed to test ideas, not verify rules. The main purpose of these investigations is to help students propose explanations for phenomena based on evidence and logic rather than their previous beliefs. All such activities should provide students with an opportunity to reflect on the concepts that guide the inquiry.

Several teaching techniques can be used to foster inquiry learning. They include the use of small-group discussions, written student explanations, student use of models and diagrams, and the development of student-generated concept maps. The level of discussion and written explanations, according to the NSES, should focus on questions such as

- How do you know?
- How certain are you of the results?
- Is there a better way to perform the investigation?
- How would you explain this to someone who had no knowledge of the phenomena?
- Is there an alternative explanation?
- Should you repeat the investigation?
- Do you need more evidence?

It is obvious from these questions that the new emphasis in the learning experience is on the student. Nowhere in the NSES does it suggest that the teacher should review the need for additional information or that the teacher should demonstrate an alternative method to gain needed information. The NSES make it clear that the student is the center of attention and activity in inquiry learning. So what then is the teacher's role?

The Role of the Teacher

In inquiry learning, the teacher is more than "a guide on the side," cheerleader, or tutor during the student investigations. The teacher is the architect of the entire experience. The same teaching skills that have always been a part of successful teaching are still needed in inquiry learning, but they are put to use in a different fashion. For example, teachers who understand where and why students have difficulty learning a specific concept can use this knowledge to assign a specific inquiry-based activity that will address known student misconceptions. An activity designed to bring misunderstandings to the surface of the student's consciousness permits students to confront their misconceptions while doing the activity. In addition, the teacher can engage students in learning while interacting with members of small groups.

The teacher is not superfluous in inquiry learning. On the contrary, the teacher is the one who facilitates the student's success in analyzing the concept. Couldn't this be done just as effectively if the teacher told the "complete story" of the concept, including pointing out common misunderstandings to students?

To answer this question, reflect for a minute on how effective the method of telling the student the "truth" and pointing out common "problems" has been in the past. How often have you done exactly that, only to find that on the test, many of your students made the same classic mistakes you had previously pointed out in class? If you are still not convinced, try interviewing a subset of your students, asking them to use their own words to explain a concept that you have already covered in class. Then have them apply this concept to a new situation. The results of this experiment can be a real eye opener for teachers.

At Catholic University, we have helped teachers conduct just this type of exercise as one component of a team action research project (Bunce, 1996). Ten teachers developed a common set of three two-week curriculum modules on states of matter, solutions, and stoichiometry. Each teacher taught the modules to his or her own classes. After students had taken the final test on a module, another teacher in the group interviewed a number of the students individually. The interview consisted of presenting a short (but new) chemical demonstration illustrating the concept on which the students had just been tested and asking each student to explain what was happening chemically. Teachers were amazed at how incomplete the students' understanding of the concept was. Repeatedly, teachers remarked that they really thought their students had learned the concept, because the students had done so well on the test. Here was a strong indication that these "learned" concepts were not really incorporated into students' understanding.

One of the methods used frequently in inquiry teaching is the discussion. Small-group discussions are led by the students. Often the teacher will want to survey the small groups and, through a class discussion, synthesize the common understanding of the concept being investigated. Many science teachers are uncomfortable with the idea of conducting such a discussion. It seems so much easier to have the groups report and then just tell them who is right and who isn't. This approach to class discussion can completely undermine the success of small-group interactions. From the students' point of view, it is easy to see that, when faced with a difficult problem to analyze, students could just wait until the "correct" answer is given in the full-class discussion. The dilemma for teachers is how to conduct the full-class discussion in such a way that students' efforts in the small groups are not undermined.

Some guidelines for an effective full-class discussion can be gleaned from the Schaible and Rhodes report (1992) of an interdisciplinary science and literature course they teach. The class of 35 students is taught in a discussion format with both the chemistry and English faculty members present. To ensure that students are both well prepared and motivated to participate in class, the authors have instituted the following discussion guidelines:

- All students must come to class prepared to lead a discussion. This could include making a list of the important ideas or themes in a reading and then writing a brief introduction expressing these ideas as questions for discussion.
- The choice of student discussion leader and two associate leaders for each class meeting is done by lottery at the beginning of the class. This approach requires each student to be prepared to take a leadership role in each class.
- Once the discussion begins, the student discussion leader's task is to keep it focused on the topic of the day.
- The faculty members must remain silent for the first 35 minutes of the 75-minute discussion. This ensures that the students will carry the discussion and not just wait for the professors to tell them what they should know. In addition, the authors note that student-led discussion results in more periods of silence. Periods of silence can be used to an advantage when they encourage students to formulate more thoughtful answers or encourage students who are more quiet by nature to participate.
- During the second half of the discussion, teachers join in as participants. This approach provides teachers with an opportunity to hear what students have to say first and then formulate questions to help students focus on some important ideas they may have missed or misconstrued.

Although not all aspects of this interdisciplinary course experience may apply to the class discussion inherent in inquiry learning, the idea that students must be prepared to lead the discussion, and that teachers refrain from the initial directing of this discussion, can offer some helpful insights on how to bring the goals of inquiry learning to the full-class discussion.

Some Examples of Inquiry Teaching

Inquiry learning activities can take place in the laboratory and the classroom. There are several excellent examples in the literature illustrating open-ended and guided inquiry laboratory investigations. The difference between these two options seems to be that of degree. Open-ended inquiry is less structured and more student-directed, and guided inquiry is more structured and less student-directed.

Bell's *Chemical Explorations* (1993) lists many guided inquiry labs that can be performed in small-scale format. Small scale has the obvious advantage of reducing both the amount of chemicals used in the lab and the chemical waste produced as a result of these experiments. Also, small-scale activities can be done quickly and repeated.

When the equipment used includes well plates and pipets, rather than expensive and exotic-looking glassware, students seem to be less intimidated. This often results in a willingness on their part to modify an experimental design or repeat an experimental procedure.

Several college chemistry faculty members connected with the American Chemical Society (ACS) Division of Chemical Education's Task Force on General Chemistry Curriculum (Lloyd, 1994) have published the results of their efforts to change standard undergraduate laboratory experiences into inquiry investigations. The laboratory program at the College of the Holy Cross (Ditzler and Rucci, 1994) emphasizes a guided discovery approach that consists of three parts: a pre-laboratory discussion that helps define the question, a small-group division of labor in the laboratory to investigate the question, and a post-laboratory session where the interpretation of pooled data and a discussion of their significance take place.

Switching from a traditional verification laboratory activity to a guided inquiry experiment can seem a little overwhelming at first. Allen et al. (1986) offer this advice:

- Choose a lab experiment that addresses simple and straightforward concepts.
- Collect data using uncomplicated apparatus whenever possible.
- Choose to collect data that lend themselves to the determination of a mathematical relationship and, whenever possible, design the experiment so that class data can be pooled.
- Modify the introductory laboratory material so that the concepts of the lab are not stated definitively in the beginning material.
- Reduce the detailed procedural steps of the experiment, and replace them with opportunities for students to think about the data they should collect and how they will do this.
- Include a verification step toward the end of the laboratory.
- Include questions at the end of the laboratory that make the students think, not just recount procedures they have used.

The authors' main thesis is a good one, that is, start the change to an inquiry learning approach by modifying existing laboratory activities. This will give you a basis for the inquiry lab, and help ensure that you are covering the important concepts in the course.

Inquiry learning can also take place in the classroom. Lord (1994) describes the use of inquiry learning to teach undergraduate biology in a two-year college. Students are first shown a clip from an old horror movie, where a glob multiplies and divides with such rapidity that it threatens to take over the Earth. Students are then given materials, such as a ruler and a box with an inflated balloon squeezed into it, and

asked to determine different ways the surface area could be calculated. This activity helps students discover both successful and unsuccessful ways of determining surface area. At the conclusion of this activity, the results are tabulated, compared, and analyzed. Students are then given a multipart question to work on in small groups that will lead them through an analysis of a projected photomicrograph. This is followed by a large-group discussion of small-group results, leading to consensus on the important concepts.

The teacher's role in these activities is essential. In addition to designing the activity, the teacher spends the time in class actually teaching (interacting with students) as opposed to lecturing (talking to students). Here the teacher creates an opportunity to find out how the students are thinking about a topic and what logic (or lack of logic) they are using to arrive at a conclusion. Everyone in the class is actively working in this inquiry-learning scenario, not just the teacher. In such an environment, it is harder for students to sleep, daydream, work on an assignment for another subject, or pursue social plans! There is a goal to be accomplished, and everyone's input is needed.

Inquiry learning using both small-group classroom investigation and cumulative full-class discussion has also been used in the ACS course for college non-science majors, *Chemistry in Context* (Schwartz et al., 1994). In the first activity in this book, "Consider This: Take a Breath," students are asked to determine how much air they inhale, both in a single breath and in a 24-hour period. Simple materials, such as gallon-size plastic bags, rulers, and a 36-inch piece of string, are given to each self-formed group of two. Additional equipment is provided at the front of the room for those groups who want it: buckets, empty 2-liter soda bottles, water, and Tygon® tubing. Students are given half the period to devise and implement a plan. The teacher's role is to circulate around the room, encouraging and asking probing questions of students to help them get started. When all groups are finished, the class data are compiled.

The volume for a single breath is typically reported in a variety of units, including milliliters, liters, quarts, cubic feet, cubic inches, and occasionally square inches! When the class is asked to vote for the correct answer, the first problem they encounter is the fact that they are comparing quantities with different units. After a suggestion that is usually made by the students, all volumes are converted to a common unit for comparison. Typically, that unit is liters. Next, the information is either analyzed or graphed. With either a mean or a mode identified, students are asked to explain possible reasons for the range of answers in the class. Usually the idea of different sizes of individuals measured, or accuracy of experimental design, is suggested. Students whose answers differ significantly from the most common answer are then asked to present their experimental designs. This usually leads to a class discussion about precision and accuracy. Finally, a question is asked about the variables that could have affected the results. In addition to experimental design, the size, health, and athletic ability of the person measured are usually suggested, along with the idea that the volume of breath is dependent on whether the person is resting or exercising during measurement. When the discussion has ended, the concepts of scientific method, research design, measurement, interconversion of units, accuracy and precision, identification, and control of variables are reviewed. The most important result of this inquiry activity is that students learn on the first day of class that they are capable of thinking scientifically and that science can be performed with simple materials.

Some Unanswered Questions

Are the standards for inquiry achievable? Can we teach inquiry learning in our science classrooms and still teach the body of science knowledge? Will students really learn anything if we make the switch? Will we as teachers still have a role to play in the inquiry classroom? Will students benefit from having the learning process focused on them in the classroom?

Although it is tempting to try to answer these questions, in the true sense of inquiry learning, I invite you to introduce an inquiry approach into your classroom on a limited basis, and evaluate the results yourself. With this firsthand knowl- edge, you may find that the answers to these questions are self-evident.

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CHAPTER FIVE

Mystery Powders: An Inquiry Activity

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Mystery powder (or solution) identifications are fun and motivating for many students, giving them an opportunity to develop and practice good deductive skills. Many students complete the identifications very successfully. However, without explicit attention to the chemistry of the systems, students do not necessarily learn any chemistry or use the chemistry they already know. Therefore, it is important to build in opportunities for students to learn and/or exhibit chemical knowledge when using these activities.

In the example presented here, the chemical concepts involved include acids and bases, gas formation, complexation, state changes, solubility, and reaction rate. The activity can be used as a way to introduce some or all of these concepts and should be followed by other activities to broaden and deepen student learning. Alternatively, the activity can be used to assess how well students are able to apply their previous learning of these concepts. You could, of course, choose a different set of samples and reagents to illustrate other concepts pertinent to your course.

This activity is designed to be done by students in groups of three or four. The group provides colleagues with whom to discuss strategies and procedures and spreads the work required to analyze the chemistry of the procedures used. The scenario given below is presented to the students to guide their inquiry. The students are free to devise their own procedures and solutions, but the problem itself is not student-devised. Material in brackets in the scenario is for your information, not part of what students have to see (although there is no reason why they should not).

Scenario
To: Your Crime-stoppers team
From: Crime-stoppers headquarters
Re: Identification of white powder evidence

We have a problem. A valuable art object has been stolen from the home of a wealthy collector. We have three suspects, all of whom claim they are innocent. The names they gave are M. R. Kleen, P. Barry Dobois, and Elizabeth C. Rocker, but we think these may be aliases. The only clue we have that might help to identify the perpetrator is a very small amount of white powder found on the pedestal where the stolen object was displayed. Under a hand lens, it looks as though the powder could be a mixture of two substances.

Unfortunately, our analyst disobeyed laboratory rules, tasted one of his samples the other day, and is now in the hospital. We need your help quickly. We have sent you a kit of supplies and samples of seven white powders, each a common household substance (see next page), which we think might be among the substances in our crime scene evidence. Please use the available test reagents and materials to work out a procedure for analyzing our white powder evidence and identifying its constituent(s). The procedure has to be as efficient as you can make it, since we have only a very small amount of the evidence. Please write up your procedure very clearly and in detail, since we will have to follow it without the help of our analyst. We look forward to receiving your procedure as soon as possible.

Kit

- 5 thin-stem plastic pipets,
- 10-12 wooden microspatulas (flat wooden toothpicks), and
- 7 white powder samples in tubes with color-coded caps (each sample is about 0.5 mL of solid): baking powder, baking soda, sugar, flour, Equal® (aspartame sugar substitute), washing soda, and a calcium supplement pill (crushed). These are most easily distributed in plastic zipper-lock bags.

Reagents and Materials

- water,
- phenolphthalein in water/alcohol mixture [Crush one Ex-Lax® tablet, mix with 10-20 mL rubbing alcohol (91% isopropanol formulation), allow to settle for several hours, and filter through filter paper or paper towels. Dilute to about 250 mL with a mixture of about half water and half 91% isopropanol. This is enough for at least 50 groups, each using one pipet filled with the reagent],
- white vinegar [5% acetic acid (CH_3COOH) in aqueous solution],
- iodine in water/alcohol mixture [Mix 5 mL tincture of iodine from the drug store with 250 mL of water. Store in a glass bottle. Iodine dissolves readily in the plastic pipets, so they will become discolored as they are used to hold and dispense this reagent],
- 91% isopropanol,
- waxed paper or an overhead transparency sheet for each group,
- paper towels for cleanup and as a background to see colors
- paper/laboratory record book to record observations, reasoning about an identification protocol, and the procedure to be used for the identification.

Expected Results
Students should not be told the testing procedure to use with their known samples and the reagents; but the small amounts of sample powder, toothpicks as spatulas, the pipets, and the waxed paper should lead them to think about observing what happens when a drop or two of liquid reagent are added to a very small amount of powder on the waxed paper. This will be especially true if they have had experience with such small-scale tests before. Addition of one drop of liquid reagent to a very small quantity of the solid should give the results shown in Table 5.1.

Expected Results of Mixing a Drop of Liquid Reagent with Each White Powder Solid					
	WATER	**PHENOLPHTHALEIN**	VINEGAR	IODINE	**ALCOHOL (a)**
Baking Powder	Vigorous gas evolution (fizzing)	Vigorous gas evolution (fizzing)	Vigorous gas evolution (fizzing)	Vigorous gas evolution (fizzing); blue-black color	Little apparent reaction
Baking soda	Little apparent dissolution *(b)*	Little apparent dissolution *(b)*	Vigorous gas evolution (fizzing)	Little apparent Dissolution *(b,c)*	Little apparent reaction
Sugar	Solid dissolves	Solid dissolves	Solid dissolves	Solid dissolves *(c)*	Little apparent reaction
Flour	Little apparent dissolution *(b)*	Little apparent dissolution *(b)*	Little apparent dissolution *(b)*	Blue-black color *(d)*	Little apparent reaction
Equal®	Solid dissolves	Solid dissolves	Solid dissolves	Blue-black color *(d)*	Little apparent Reaction
Washing Soda	Solid dissolves	Solid dissolves; red color	Vigorous gas evo-lution (fizzing)	Solid dissolves *(c)*	Little apparent reaction
Calcium Supplement	Little apparent dissolution *(b)*	Little apparent dissolution *(b)*	Little apparent dissolution *(b)*; slow gas evolution (bubbles)	Little apparent dissolution *(b,c)*	Little apparent Reaction

(a) Little or none of these white powders dissolve in alcohol or give any apparent reaction.
(b) Solid appears not to dissolve completely or at all.
(c) The initially orange liquid will lose color over a few minutes. See the text for an explanation of this observation. Students should be encouraged to observe a drop of each reagent without any of the solids present to see what happens to them over time.
(d) The blue-black color is so intense that it usually masks what is happening to the solid. To produce a solution that is less dark, a more dilute iodine solution could be used.

Assessment/chemical knowledge
To assess how well a group's analysis procedure works, have groups exchange procedures. Each group now follows another group's procedure exactly as written to analyze an unknown binary mixture you have furnished. Be sure that each group is aware that they are to do only what is written in the procedure. Remind them that the "analyst" is in the hospital, and the procedure is being carried out by someone or some group who can only follow the directions, not interpret them.

Having groups exchange procedures will help you assess how well the students can explain how to carry out a procedure and may even make you more aware of the care that has to be taken in explaining exactly how to do something. Common omissions in the procedures will probably be missing directions on how much solid sample to use (or even omitting the direction to take a sample) and/or how much liquid reagent to use. If problems with the procedures are apparent, they can be returned to the original groups for rewriting before another round of exchange and analysis is tried.

If you are using this activity as an introduction to the chemical principles involved in the changes observed in the tests, it is a good idea (perhaps before carrying out the exchange of procedures and analysis) to have each group do a bit of research in the library or their textbooks to discover the chemical basis of the changes and to include the results of their research in a write-up of their results from the tests on the known solids. If this activity is used to reinforce previous learning and to help you assess it, each group could report on the chemical basis for the procedure used to determine the identity of the components of their unknown mixture. They would be reporting on the analyses and the rationale chosen by another group.

Although the following is not an inclusive sketch of the chemistry involved in the interactions of these solids and liquids, it touches most of the high points.

Acids and Bases
Phenolphthalein is an acid-base indicator that turns from colorless below pH 9 to red (pink to purple, depending on its concentration) between pH 9 and 10. Baking soda (sodium bicarbonate, $NaHCO_3$) dissolves enough to give a weakly basic solution around pH 8; it doesn't produce a red color.

Washing soda (sodium carbonate, Na_2CO_3) dissolves to give a very basic solution at pH 12 or above; it gives a red color. Washing soda is so named because it is used together with soap to produce the basic solution in which soap works best; the "builders" in detergents are there for the same purpose. Although in principle the calcium carbonate ($CaCO_3$) in the calcium supplement would also give a basic solution, it is so insoluble in water that not enough dissolves to raise the pH above 9.

Gas Formation
All gas-forming reactions in this system are also acid-base reactions involving carbonate or bicarbonate compounds reacting with an acid to produce carbon dioxide gas. Vinegar is a solution of acetic acid that reacts with baking soda, sodium carbonate, and baking powder to produce vigorous gas evolution (fizzing). It reacts more slowly with calcium carbonate because the solid is quite insoluble, and the production of gas is limited by the rate on the solid surface or with the small amount of carbonate that dissolves.

Baking powder is an interesting case, since vigorous gas evolution is observed when any aqueous solution is added to the solid. Baking powders contain sodium bicarbonate, which is the source of the gas. They also contain a solid acid, for example, calcium dihydrogen phosphate $[Ca(H_2PO_4)_2]$, which can react with the sodium bicarbonate when the two are dissolved in water, and the aqueous acidic ion $H_2PO_4^-(aq)$ ($\rightarrow H^+(aq) + HPO_4^{2-}(aq)$) produces an acidic solution. The reaction of baking powder with vinegar presumably involves both this kind of reaction and the reaction of the bicarbonate with acetic acid.

Complexation
In solutions that contain iodine (I_2) and iodide ion (I^-), starch reacts to form a complex containing mainly I_5^- ions trapped inside coils formed by the long glucose polymer chains of which starch is made. This complex is an intense blue color that looks black when a lot of I_2 is present to form a lot of complex. Students can test this by successively diluting an iodine-iodide solution ("tincture of iodine" is such a solution in alcohol), adding a drop of each successive dilution to a tiny bit of flour or cornstarch, and observing the colors. Flour contains a great deal of starch; you would expect it to give the starch-iodine reaction. Baking powder and Equal® are a bit surprising until you read their labels. Baking powder has added starch, probably to improve its flow characteristics and help prevent its clumping. Equal® has added "maltodextrin," partially broken-down starch, also probably to improve flow characteristics and to give bulk to the product because so little sweetener is actually present. What other common foods might also contain starch?

State Changes
Assume that the testing is done using drops of the liquid reagents with tiny amounts of the solids. Students will almost certainly notice that the iodine solution mixed with a solid that doesn't give the starch test remains a light orange color at first but slowly fades to colorless. What happens to a drop of the iodine solution that is not mixed with a solid? Exactly the same thing. The iodine is volatile enough that it escapes from the solution as a gas. There is so little of it that it is invisible in the gas phase. Iodine also dissolves well in all sorts of organic materials, including the wax in waxed paper and the plastic in plastic containers. The change of state (solute to gas) or the change of solvent (water to organic) explains the slow disappearance of the color from the droplets of aqueous iodine solution.

Solubility
No consistent solubility "rules" are apparent from these results, except that alcohol is not as good a solvent as water, since little solubility in the alcohol is apparent, whereas some of the solids (sugar, Equal®, and washing soda) readily dissolve in water. High molecular weight polymeric compounds like starch tend to be insoluble, and flour does not appear to dissolve. However, sugar, a moderate molecular weight compound, dissolves readily. Carbonates tend to be insoluble (the calcium supplement, mostly calcium carbonate), but sodium salts tend to be soluble (washing soda, sodium carbonate). Some standard rules are *exemplified* but cannot be *derived* from this very limited set of reagents. This is a good activity to get students thinking about what kinds of substances are soluble and insoluble and have them begin to look elsewhere for patterns and rules.

Reaction Rate
The most striking examples of reaction rate changes in this activity are in the gas-forming reactions. In some cases the gas evolution is so rapid that the solution fizzes. In another case, the reaction is so slow that individual bubbles can be seen forming. In the case of *dry* baking powder, the reaction of the solid acid with the solid bicarbonate is so slow that the mixture can be kept unreacted for months or years. The acid-base indicator reaction and complexation of iodine by starch are so rapid as to appear instantaneous.

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CHAPTER SIX

Planning Lessons and the National Science Education Standards

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Deciding what students should know and what students should be able to do is a fundamental task facing science teachers across the nation. The amount of guidance teachers are given varies dramatically from school to school. In some cases there are comprehensive and complete plans that guide what happens in every science classroom from primary through secondary levels. More often than not, the individual teacher is left to decide what content is covered and what instructional methods are employed. Many states now have a framework that is designed to serve as an overarching plan to guide school districts, individual schools, and teachers in planning their lessons. The degree to which teachers actually use these guidelines in planning their lessons varies widely. Clearly, teachers need the right tools and information available before they will begin to make lesson plans based on external standards.

One component that has been missing until recently is a set of national standards for science instruction. With the publication of the National Science Education Standards (NSES) by the National Research Council, there is now a set of guidelines for what students should know and what they should be able to do as a result of 12 years of science instruction.

Despite clear and comprehensive standards at the local, regional, and national levels, a gap remains between the published standards and their actual implementation in individual classrooms. What happens when teachers close their classroom doors remains largely in the hands of the teachers. If we as teachers would like to embrace the content and methods outlined in the national standards, what kinds of changes should we make in our lesson plans?

The Teaching Standards

The standards make some substantial suggestions relative to the teaching of science and the kinds of lessons we should present (see Table 6.1).

This is not to say that many lesson plans are not already doing work as set out in the NSES. The goal is to have science teaching and learning uniformly embody the traits listed below, but not be exclusively limited to them. The recommendations in the NSES are consensus statements (yet they may still be controversial to some). Most experienced science teachers will recognize the emphasis on practices that have been shown to be effective in teaching science to a range of students.

Table 6.1
Changing Emphasis in Lesson Plans

Less Emphasis On	More Emphasis On
Lesson plans that present content only and rely on student' ability to recall facts	Planning an inquiry -based science program
The "sage on the stage" approach, where the activities are all centered on the teacher	Teachers who present lessons that guide and facilitate student learning
Lessons that lead to cumulative exams, although the lessons themselves are never evaluated	Plans that include an ongoing assessment of teaching and learning
Set blocks of time and lessons that require all students to learn at the same rate	Plans that allow for providing students enough time, space, and resources to learn the science
Plans that have students working alone or in unrelated groups	Lessons that incorporate cooperative learning and collaboration among students

The more difficult task is to actually craft lessons that help students achieve the learning goals of the NSES. The rest of this article focuses on specific examples of lesson plan elements that will address this task.

Mastering Content vs. Inquiry-Based Learning

One of the factors that draws many students to study science in the first place is the natural curiosity children seem to possess. They are born scientists and love to find out about how things work by "messing around" with them. The inquiry described in the NSES is not the inquiry-based learning of the Sputnik era. Students are not expected to derive first principles. Current inquiry-based lessons present focused questions and allow students to have a role in how best to answer them.

Table 6.2
Content-Based Cookbook lab vs. Inquiry-Based lab

Do Less of This	Do More of This
Students are given a four-page handout for a lab designed to determine the formula of a hydrate. All background, procedures, and safety precautions have been prepared for the student. The student follows the procedures, fills in the data and turns in the worksheet. The teacher grades the lab; the class moves on.	Following instruction on the concept of a hydrated compound, students are challenged to determine experimentally the formula of a compound with an unknown number of waters of hydration. Each student is given a sample. Students are asked to write out a procedure (including research on safety issues) that must be approved before they begin. Students are not abandoned in this effort. The teacher acts as a facilitator, advising students as to what essential measurements must be taken, discussing the merits of sample size, suggesting equipment that is available for use in the experiment. Class discussions can resolve issues such as knowing when all the water has been driven off. Students design their own date table. After calculations are finished and results are known, students with superior results explain how they did the experiment. The teacher coaches poor performers on how they can improve their results. The experiment is repeated.

As Table 6.2 illustrates, all too often the "cookbook" labs we use for lessons in science instruction take the student out of any active, thinking role in the exercise. The teacher decides what questions to ask, procedures to follow, controls to observe, safety precautions to note, and may even go so far as to prepare a data table or worksheet for the student to fill in. This occurs in spite of the fact that most science teachers cite thinking and inquiry as extremely important skills for students to practice.
As shown in Table 6.2, students in the inquiry-based lab get a chance to participate in the most important parts of the lab exercise. They decide how to make the measurements, and they also get a chance to decide what the results mean. (If the teacher always writes the procedures to be followed, it eliminates what little real scientific investigation may have been present in the first place.) The student's procedure may be flawed. This is an acceptable occurrence. Ideally, by comparing the end results with various other student approaches, students will hone their ideas of what makes an effective experimental strategy. In straight cookbook labs, this issue would never even come up.

When a student is involved in creating an experimental design, the level of interaction between the teacher and the student changes dramatically. Instead of questions such as 'What do I do next?" the student may say, "I'm wondering if I can improve my results if I try it this way." The interaction is much more meaningful.

Table 6.3
Chemical Equilibrium Lecture and Problem Sets vs. a Constructivist Approach

Do Less of This	Do More of This
The chemical equilibrium lecture centers on chemical equations. The teacher explains rate expressions, and factors that affect forward and reverse reactions. Calculations of K_{eq} are made. Le Chatelier's principle is defined by the teacher, and students make predictions of equilibrium shifts on the basis of hypothetical changes of reactants, products, and conditions.	The teacher poses the problem of reversibility of reactions. The question might be phrases, "If the rate of forward reaction is somewhat faster than the reverse reaction, will the system ever come to a balance or equilibrium?" Students are given two graduated cylinders: One is nearly full, the other empty. They are also given two straws with different diameters, but equal lengths. The model reaction consists of transferring liquid from one cylinder to the other. The student transfers the liquid by inserting the rod to the bottom of the cylinder, covering it with a finger, and moving it to the other cylinder where the liquid is released. One size straw is used to go from the first to second cylinder, and the other is used only for second-to-first transfers. Students begin transfers, measuring the amount left in each cylinder after every three transfers. The students are told to call the instructor when they achieve equilibrium. Many students have a misconception that equilibrium will mean equal amounts in each cylinder, but the amounts keep changing past that point. Students finally recognize equilibrium when the volume of liquid transferred back and forth is equal. The teacher guides students to recognize equilibrium as balanced opposing reactions.

Teacher-Focused Activities vs. Guided Learning
Most of us teach as we were taught. All too often that means a predominance of lecture and direct presentation of content. There is a certain false efficiency in lecturing to teach content. The teacher can control the time and the sequence of facts presented. Student behavior is predictable and subdued. There is an appearance of learning. Many new teachers are shocked when they first discover that even though they explained the mole concept perfectly, it did not mean that the students learned it perfectly. It is the wisdom of the Chinese proverb "I hear—I forget; I see—I learn; I do—I understand."

The standards suggest an approach based on constructivist theories of learning. The idea is to direct the students along the path to knowledge rather than simply telling them facts to remember. For example, once the students have a good conceptual understanding of equilibrium, the model in Table 6.3 can be interpreted in terms of real chemical reactions. The relationship of rate constant times concentration can be analogously compared to the diameter of the tube times the height of the column of liquid. In the first case in the table, the students memorize a definition. In the second, they construct a definition of equilibrium for themselves.

Cumulative Exams vs. Ongoing Assessment and Evaluation of Lessons
The standard of instruction in many classrooms tends to be derived from the college habit of having two midterms and a final. This is occasionally modified to include end-of-chapter exams, followed by an end-of-term cumulative exam.

The NSES suggest that teachers use multiple methods to gather information about their students (Table 6.4). The assessment of students is also taken as a measure of the efficacy of the instruction. If many students fail, the lesson is reexamined, revised, and retaught. Teachers can use this experience to change their teaching styles and methods to more effective strategies.

Assessing student knowledge is one of the most difficult parts of teaching. Teachers may feel compelled to give end-of-chapter or unit tests simply because nearly all commercial textbooks are written to include this traditional type of testing. Furthermore, it is the system they know. Little in real life is assessed in the fashion we typically use to assess science learning. Consider how we assess the ability to drive a car. We do not drive for a month and then take only a written exam on what we learned. Rather, each driving experience is judged and evaluated on the basis of our performance and reactions. Another example might be the practice of medicine. Physicians evaluate their learning by considering the results of each patient case and the outcome of each diagnosis and treatment. Our interactions with students should be more like this. We need to assess student learning at each application of knowledge they present to us. Completion of a well-designed experiment, where the interpretation of data matches the conclusions drawn 'by the student, should provide as powerful an evaluation as any kind of traditional written exam.

Table 6.4
Energy and Order: End-of-Unit Testing vs. Varied and Ongoing Assessment

Do Less of This	Do More of This
Students are given two weeks to study the content standard related to conservation of energy and the increase in disorder. They do assignments, have lectures, do labs, and write research papers. At the end of two weeks, they are given a multiple choice test. their grade for the unit is based on primarily on their score on this test.	During the two week unit on energy, student assessment is varied and ongoing. After the first reading assignment, students are given a brief oral exam to assess their understanding of the reading. During lab, the instructor inspects students for safe and accurate lab techniques and notes them. Students are asked to prepare a concept map of the content and explain their thinking to a small group. The group gives feedback and the student does a self assessment on the explanation's quality. A short objective exam is given at the end of a particularly difficult section of content. The results are used in the decision to carry on or review. The final grade is a combination of all the grades earned during the unit.

All Students at the Same Rate vs. Allowing Students Enough Time and Resources to Learn Science

No more difficult task faces classroom teachers than ensuring that all students learn in a set time, when all students do not learn at the same rate. The NSES are based on the principle that *all* students can learn, can understand, and can do science. This means that the practice of having only a fraction of the students competent by the end of a chapter must end.

One implication of this is that class management and record keeping must also change (Table 6.5). Any system that only keeps track of the fraction of the learning a student was able to muster in a set time is unacceptable.

This sort of thinking runs up against some formidable obstacles very quickly. Most school systems are not set up to deal with this kind of grading or record keeping. It is possible, however, to continue instruction on new units even if all students have not met the standard. Presenting evidence of understanding might fall on the students to pursue. The teacher would only need to provide the opportunity for students to document their learning. Even so, this requires a redistribution of resources and may require faculty members to reteach topics or provide remedial help to students.

Table 6.5
All Students with Same Time vs. All Students with Same Learning

Do Less of This	Do More of This
Lesson plans call for eight days to study the structure of atoms and molecules. During the lessons, students accumulate points. They are graded on a scale that equates their relative achievement with the number of points given (90% and above is an A, 90-80% is a B, and so on). Student scores range from low to near perfect. The class moves on to the next unit.	Before the lesson is planned, the teacher decides on the critical learning that must occur. Six outcomes are chosen, and a rubric is written so both the teacher and the students know how to demonstrate the learning that has occurred. The activities proceed as before. Students do labs, read material, exchange ideas, and take exams. They also demonstrate their understanding of the six outcomes to the teacher. When each student has mastered all six outcomes, that student is recorded as having satisfactorily passed the unit. Students receive no credit for passing only five outcomes. They continue to work on the learning and have an opportunity to present evidence of learning when they are ready.

Students Working Alone vs. Cooperation and Collaboration

Every study on work force readiness in recent years has emphasized the need for employees who can work together in teams. Most production and development in industry take place in cooperative groups. New workers who cannot work in teams don't stay employed for long.

Moreover, a collaborative and cooperative "community" approach to teaching enhances learning. It helps to advance the understanding and achievement of all those involved. The evidence is clear that cooperative groups can be very effective. They have the added benefit of allowing students to be exposed to diverse ideas and modes of thinking. Community activities can lend a richness of appreciation for culturally and intellectually diverse experiences.

Science is collaborative by nature, and working in cooperative modes models all the skills, attitudes, and values associated with scientific inquiry (see Table 6.6).

In the future, lesson plans will look different if teachers are guided by the NSES learning goals for what students should know and be able to do in science. Teachers will design lessons that stop treating students alike or respond only to the group as a whole. There will be less lecture, less recitation of facts, and less presentation of science as something that has already happened and now must be remembered. There will be lessons that adapt and respond to individual student interests and abilities. There will be a focus on understanding and using scientific information and skills. Teachers will guide students to understanding and share with them the responsibility of learning. Lesson plans will encourage a classroom that is inhabited by a community of learners where everyone, including the teacher, is an active learner.

Table 6.6
Reading Assignments: Individual Work vs. Cooperative Approach

Do Less of This	Do More of This
Each student reads the assigned section of required reading in the textbook. When finished, each student completes a worksheet of review questions and turns it in for the teacher to grade.	The teacher divides students into "expert groups." Each group of experts is given one section of the reading assignment to read and study as a group. They read the material, discuss the contents, and clarify their understanding of the reading material to the satisfaction of everyone in the group. Students are then regrouped so that each of the new groups has one expert from each section of the reading assignment. The experts teach the new group about their sections of the reading. By the end of the session, all students have a good understanding of the entire assignment. They can then put their knowledge to use on the next activity.

Having the national standards in place is a significant step in reforming science education. Implementing the standards in the form of effective instruction is the next step for most of us.

REFERENCE

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

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CHAPTER SEVEN

Developing a Lesson on Changes of State

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The focus of this lesson plan is Physical Science Standard B as quoted below from the National Science Education Standards (NSES). The lesson will focus on one subcomponent of the standard only, namely, those fundamental concepts and principles that relate to changes in state. The lesson is also intended to be consistent with the teaching and assessment standards and Inquiry Standard A from the standards document (NRC, 1996). Physical Science Standard B states that

> As a result of their activities in grades 9-12, all students should develop an understanding of the structure of atoms, the structure and properties of matter, chemical reactions, motions and forces, conservation of energy and increase in disorder, and the interactions of energy and matter.

Developing Student Understanding
High school students develop the ability to relate the macroscopic properties of substances that they studied in grades K-8 to the microscopic structure introduced in grades 9-12. This development in understanding requires students to move among three domains of thought: the macroscopic world of observable phenomena; the microscopic world of molecules, atoms, and subatomic particles; and the symbolic and mathematical world of chemical formulas, equations, and symbols. Teaching about changes of state involves students in moving across these three domains.

The NSES provide a guide for each standard. Under Physical Science Standard B, the following guidance is provided relative to changes of state:

> Solids, liquids, and gases differ in the distances and angles between molecules or atoms and therefore the energy that binds them together. In solids, the structure is nearly rigid; in liquids, molecules or atoms move around each other but do not move apart; and in the gases, molecules or atoms move almost independently of each other and are mostly far apart.

Place in the Curriculum
The relationship between structure and properties is a major thread running through this standard at all grade levels from K-12. The high school science curriculum provides students with opportunities to develop an understanding of atoms, molecules, and ions and how their arrangement is related to the properties of compounds made up of these particles. This lesson plan, for grades 9 or 10, addresses the development of the idea that the arrangement of particles, and the energy that binds them together, is related to the physical state of a sample. A single lesson is not sufficient to develop a complete understanding of the relationship of energy to the behavior of particles. The concept of energy and how it applies to phase changes is particularly elusive and requires attention throughout the high school years in many contexts. Students need to be involved in a wide variety of meaningful investigations over a period of years to develop understanding.

Before instruction begins, students should understand the concept of density, that matter is made of small particles, that potential energy is energy of position, and that kinetic energy is associated with moving objects.

Students should be able to describe observations orally and in writing, use balances to measure mass, use graduated cylinders to measure volume, calculate densities of solids and liquids, and work effectively in a large group (whole class), small group (four to five students), and individually. Students do not need to understand atomic or molecular structure before this activity.

Students may hold naive conceptions, including the notions that particles of a solid are much closer together than the particles of a liquid, gases do not have mass, gas molecules expand to fill the space when a gas changes to a liquid, or that some substances such as iron are always solids, whereas others are always liquids or gases.

In the following lesson, it is assumed that students are accustomed to working productively in small groups and to accepting individual accountability as well as group accountability. They know how to use textbooks as reference materials, how to write a procedure for a laboratory investigation, how to construct written and oral reports to communicate laboratory results, and how to participate in a whole-class discussion.

Engaging the Interest of the Class
Assemble the class as a committee of the whole. Use one or more of the following suggestions to engage the interest of students in the topic of the lesson. You may have other favorite demonstrations, games, videotapes, or computer simulations that you could use. This segment of the lesson is intended to get students interested, not to impart information or facts. This may be the most important part of the sequence.

- Show descriptive portions of the "The World of Chemistry: States of Matter" videotape. At this time, do not show the portion of the tape devoted to models. (Students will develop their own model during the activity.)

- Show videotape or still photographs depicting water in solid, liquid, and gaseous states. (TV stations can sometimes be persuaded to contribute such footage from their weather programs.)
- Place 600 mL water in each of two 1000-mL beakers. Put one beaker on a hot plate and heat until the water boils. Ask students to observe carefully and record their observations. Put an ice cube in the second beaker and ask students to describe the differences between ice and liquid water.
- Locate photographs or videotapes of changes of state of other substances, such as liquid iron formed during the refining process or liquid glass formed in the manufacturing process.
- Demonstrate some of the properties of liquid nitrogen or dry ice. (Dry ice can sometimes be obtained from ice cream stores, and liquid-nitrogen may be available from welders or veterinarians.) Many demonstration books have suggestions for demonstrations using these two materials.

Asking the Questions
Assemble the class in groups of four or five. Tell each group to make two lists: one of facts they already know about changes of state and the other of questions they have about changes of state. Provide a place on the chalkboard (or give each group an overhead transparency) for use in sharing the lists. This activity will probably take about 15 minutes, but let the discussions continue as long as they are productive. Eavesdrop on the discussions, but try not to be drawn into contributing to the discussion of a group.

Reassemble the class as a committee of the whole to examine the lists. Facts on one list may be questions on another list. This is a good place to uncover naive conceptions. Ask the class to phrase items from the lists so that they can be investigated in the laboratory. Small groups now plan an appropriate laboratory activity to investigate one of the questions. Remind students that chemistry is a quantitative science, and suggest they measure variables whenever this would contribute to their investigation. The sophistication of the questions will vary with the background of the class and the experience they have in framing questions in this way. Questions that might be listed include

- What happens to the temperature when water boils? Freezes?
- What is the gas produced when water boils?
- How much energy does it take to melt an ice cube? .
- Do all liquids evaporate at the same rate?
- How do the densities of solids, liquids, and gases compare?

Collecting Data
Each group of four or five prepares a written procedure, including numbered steps to use in the investigation, safety precautions, and a list of equipment and materials needed for the investigation. This part of the lesson could be a homework assignment. Read the procedure, safety precautions, and equipment list carefully, and make necessary suggestions without changing the intent of the students' procedure. After approval of the procedure, the group separates into two laboratory groups to carry out the investigation independently, reassembling to discuss and interpret the two sets of results.

Explaining the Results
Now is the time to go to textbooks and other references to help explain the laboratory findings. Each group of students prepares a written and oral report to describe their investigation and communicate the meaning of the results. (These reports can also be used as part of the evaluation of this lesson.) Students should be encouraged to include visual aids in their oral presentation. Following the oral presentations, the class together develops a model for solids, liquids, and gases. Ask how they would visualize particles of gases, liquids, and solids if they could see individual molecules, atoms, or ions. Each group then adds a section to their report to explain their laboratory observations using the model developed by the class.

After the class develops its own model, you may wish to share particle models developed by others, such as those in ICE Software, University of Wisconsin, Madison; in the videotape, "The World of Chemistry: States of Matter"; and in various chemistry textbooks. Review the major postulates of the kinetic molecular theory for gases. Have the students work individually on the following questions that focus on adapting the kinetic molecular theory to explain properties of solids and liquids:

- How does the arrangement of particles change when a solid changes to a liquid?
- Why does the temperature remain constant while a solid is changing to a liquid?
- In order to change a solid to a liquid at its freezing point, energy must be added. What changes take place because of this addition of energy? What happens to the freezing point?
- Answer the above questions for changing a liquid to a gas.
- Which should require more energy, changing a solid to a liquid or changing a liquid to a gas? Explain your answer.
- Use words to describe a particle model for solids, liquids, and gases.
- Potential energy is energy of position, and kinetic energy is energy of motion. How are each of these related to the behavior of the particles during changes of state?

It is possible, but not necessary, to use any of the following to extend the lesson (let the ability and interest of your class be your guide):

- calculations involving ΔH_v and ΔH_f,
- calculations involving cooling curves,
- relating the strength of intermolecular forces to boiling point and ΔH_v ,
- the relationship of phase changes and weather changes, and
- crystallization and the formation of rocks and minerals.

Possible Evaluation Items
One definition of understanding is the ability to apply the idea to a new situation. These evaluation items are based on that definition.

Paper—Pencil

Use the particle model to explain each of the following observations. Draw pictures and/or use words.

- A burn from steam at 100 °C is significantly more severe than a burn from water at 100 °C.
- One feels cool when getting out of the swimming pool even on a very hot day.
- Densities of substance in the solid and liquid state are nearly the same, but the density of the gaseous form of the same substance is often nearly 1000 times smaller.
- Parents are sometimes told to wash the skin of a feverish baby with alcohol.
- The ice in a pond freezes from the top down, not from the bottom up.

Practical Work

You can also choose questions from the group lists that were not investigated previously. For example, plan and carry out an investigation to compare the rates of evaporation of three liquids, or plan and carry out an investigation to determine how the volume of a liquid varies with temperature.

Demonstrations
Perform a series of demonstrations with students observing and using the particle model to explain their observations individually on paper. Suggested demonstrations are briefly described. Other suitable ones can be found in demonstration books and laboratory manuals.

- Cleave a crystal of calcite by striking it with a hammer.
- Add 50 mL water to 50 mL absolute ethanol.
- Put about 5 mL water in an empty soft-drink can. Heat the water to boiling. Quickly invert the can with tongs, and plunge the open end in ice water.
- Demonstrate surface tension by floating a needle on water.

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CHAPTER EIGHT

Putting "Life" into Chemistry and Vice Versa

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From the primordial soup (or deep-sea hydrothermal vents) to the complex processes that enable you to read this sentence, life processes are chemical processes (see Life Science Standard C of the National Science Education Standards, NSES). They are the same chemical processes (reactions) that occur in nonliving systems. To make this apparent, we need to include biological chemistry in high school chemistry courses. By doing so, we can provide an integration of the physical and the life science content standards that will enrich both. Putting "life" into chemistry, or chemistry into life, is more than simply inserting one or two examples throughout your course. Learning about the chemistry of life processes should be an integral and essential part of the content that our students are expected to understand and be able to use.

The material in this chapter is designed to help you introduce some important organic and biochemical examples into your chemistry classroom. We do not expect you to teach either an organic chemistry or biochemistry course, merely to broaden the students' understanding of the breadth of modem chemistry, the central molecular science. The examples given may be relevant to both Physical Science Standard B and Life Science Standard C. In order to introduce bio-examples into the traditional course, we will change our emphasis. The changes listed in Table 8.1 will be explored throughout this chapter.

Some Organic and Biochemical Examples

Physical Science Standard B states that an understanding of the structure and properties of matter should include the concept that "Carbon atoms can bond to one another in chains, rings, and branching networks to form a variety of synthetic polymers, oils, and the large molecules essential to life." (Note that the units in biopolymers are *not* connected by carbon-carbon bonds.) This material can be woven into the lessons you already teach, if you select appropriate examples. You do not necessarily need to teach a separate unit labeled "Organic Chemistry."

Some of the inorganic model systems we usually use to develop and illustrate important chemical principles can be replaced with biological or organic systems that serve the same purpose and reinforce the idea that the chemistry is the same wherever it occurs. This is not totally foreign territory. In discussions of acids and bases, an organic acid, acetic acid, is almost universally chosen as one of the first examples of a weak acid. Acetic acid is the end result of biological oxidation processes in wine and cider. For weak bases, the choice is almost always ammonia, a choice that is easily generalizable to amines. Acids and bases are among the chemical reactions discussed as fundamental concepts in Physical Science Standard B.

When reaction rates and catalysis are discussed (also a component of Physical Science Standard B), enzymes are almost always mentioned. Their exquisite substrate selectivity can be exploited in demonstrations and experiments to illustrate the consequences of molecular structure.

The most important process on Earth, photosynthesis, brings together reactants from the nonliving world—carbon dioxide, water, and light—into living systems and plants, to form organic compounds (simple sugars) and oxygen. An understanding of photosynthesis is a component of both Physical Science Standard B and Life Science Standard C. Examples that overlap both standards are abundant; we should take advantage of them to reinforce student learning and bring about the changes in emphasis outlined in Table 8.1.

Water-More Than Just a Solvent

Water is a very familiar but sometimes misunderstood compound. Its role in biological systems goes beyond that of the "universal solvent." For example, the formation of all "polymeric" biochemical structures (fats, nucleic acid backbones, proteins, starch, and cellulose) involves the loss of a molecule of water as each new carbon-oxygen, carbon-nitrogen, or phosphorus-oxygen bond is made. Conversely, when these structures are broken down, as they must be when they are no longer needed, or when they are used as a fuel source, water is one of the reactants. All of these bond-breaking reactions are hydrolyses.

In living systems, the hydrolysis reactions are all favored, that is, the polymeric species are unstable with respect to hydrolysis. This is one example of the universal tendency toward less ordered and less organized structures (an essential concept found in Standard B). Individual units in a polymer are strung together like beads in a necklace; the units constrain one another's movement. When the units are separated (the necklace is broken), they are free to move about unconstrained by each other.

Table 6.1
Changing Emphasis in Introductory Chemistry

Do Less of This	Do More of this
Using inorganic examples to develop chemical concepts	Using organic and biochemical examples to develop chemical concepts.
Introducing water as simply a solvent	Introducing water as a reactant and product in biochemical systems
Introducing the carbon framework and naming simple organic compounds	Introducing the structure and polarity of organic functional groups
Giving no rationalization for the reactivity of inorganic and organic compounds	Illustrating the systemic reactivity of organic functional groups

Life is possible because the hydrolysis reactions are slow in the absence of catalysts, so the polymers can exist long enough to do their jobs. A large proportion of metabolic reactions that require a source of energy get the required energy from the exothermic hydrolysis of phosphoric acid anhydride bonds, for example, in ATP, adenosine triphosphate (Physical Science Standard B and Life Science Standard C). The ATP itself is produced in other reactions that harness the energy released in the oxidation of fuel molecules from the food we eat (see Life Science Standard C). Anhydrides and their role in biological systems are not suggested as topics for inclusion in an introductory course but are mentioned here as one more example of the ubiquity of hydrolyses in life processes.

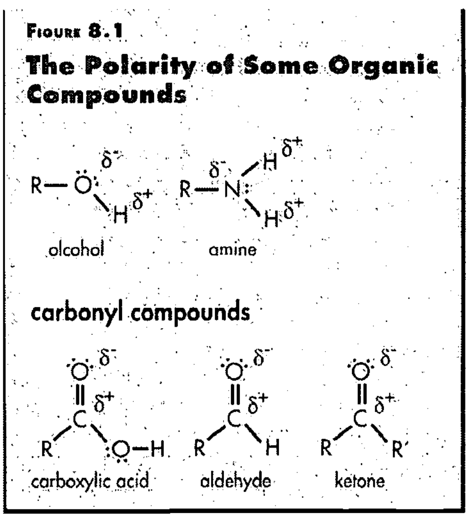
Thus, water is far from being simply an "inert" solvent for transporting species from one place to another in the organism or cell, and bringing reactants together. It is an essential participant in many biological reactions. This role of water is rarely stressed. Textbooks tend to focus on the many interesting physical properties of water (high heat capacity, high enthalpy of vaporization, expansion upon freezing, and so on) that make it a unique solvent. Even the solvent properties of water in relation to biomolecules are often ignored. Further, the essential role of water as the source of "reducing power" (hydrogen atoms) in photosynthesis is almost never included in introductory courses in chemistry or biology.

Structure and Polarity of Organic Functional Groups

It is easy to see that including more biological chemistry in the introductory chemistry course implies that more organic chemistry also has to be included so that students can understand something of the structure and reactivity of biomolecules. An emphasis on just a few kinds of compounds (alcohols, carboxylic acids, ketones, aldehydes, and amines) and their functional groups reduces the burden this places on the course. These can be introduced and used as examples when molecular bonding, structure, and geometry are developed (Physical Science Standard B).

It is particularly important to stress the polarity of the bonds in the functional groups based on electronegativity arguments, the partial charges on the atoms, and experimental evidence for polarity. The partial positive charge carried by the carbonyl carbon and partial negative charges on the oxygen and nitrogen in alcohols and amines, respectively (see Figure 8.1 below), are central to many of their reactions in living systems. Note that the diagram focuses on the functional group and not the rest of the molecule (designated as R or R'). Getting the students to identify functional groups is good practice but is a secondary concern in an introductory course.

FIGURE 8.1



However, if functional group polarity and its consequences are not emphasized in the introductory course, students are often left with the impression that organic molecules are somewhat "inert." Hydro+ carbon chains in oils and polymers do tend to be inert and water-insoluble, which is what makes them so useful as lubricants and in other everyday materials. When attention is centered on the carbons, functional groups tend to get left out because they complicate the structural picture and make the compounds hard to name. Let me emphasize that counting carbons and naming hydrocarbon chains are *not* supported by the standards and are not the appropriate chemistry for an introductory course.

When the focus is on functional groups, a different picture of organic molecules emerges. Functional-group polarity tends to make organic compounds water-soluble. Ethane, CH3CH3, is very insoluble in water; add an -OH group and the ethanol formed, CH3CH2OH, is infinitely miscible with water. Everyone knows that sugar (sucrose) is very soluble in water; sucrose has 10 -OH groups that can interact with water. Students should learn from such examples to generalize about the water-solubility of organic compounds with one or more functional groups. However, the organic generalization they usually learn is "oil and water don't mix."

If challenged, many students are puzzled by the behavior of sugar, because it is a relatively high molecular mass organic compound. However, because it does not fit the rule and is a crystalline white solid like salt, most students do not consciously think of sugar as an organic compound. Here, an obvious learning objective is a better understanding of the solvent role of water in living systems, where many of the molecules are large but are relatively water-soluble because of their functionality.

Systematic Reactivity of Organic Functional Groups

We do not intend that you go into great detail on the systematic reactivity of organic functional groups—remember that the standards are designed for *all* students, not only Advanced Placement students. However, at a minimum, your students should learn that electron distribution in molecules is responsible for chemical reactivity, and that interactions of more positive with more negative centers in atoms, ions, and molecules can be used to explain and predict the outcomes of a very large percentage of chemical reactions. The mechanistic details should be left for second-year and later courses taken by those students whose career goals include the sciences.

Functional group polarity makes organic compounds quite reactive under rather mild conditions, for example, in a living cell.

Glucose test strips can be used to test for the formation of glucose. Exploring the chemistry of various glucose tests, which usually involve at least one enzymatic reaction, could extend this carbohydrate investigation.

As part of a unit on chemical reactions, students can investigate the interfacial reaction of a diacid derivative and a diamine (the "nylon rope trick") to discover the conditions required for making the best nylon strand (Bieber, 1979).

The decomposition of hydrogen peroxide to produce oxygen and water is catalyzed by a wide variety of inorganic species and organic/biological systems. (Borer et al., 1996). Most of the latter involve the enzyme catalase, which is present in plant and animal tissues, to help get rid of the hydrogen peroxide formed in various oxidation reactions. The more catalase present in a tissue, the faster the tissue can break down peroxide.

The production of oxygen (above control levels) from a solution of hydrogen peroxide and some tissue, or tissue extract, signals the presence of catalase (or another catalyst for the breakdown). Thus, oxygen production can be the basis for an investigation of the catalase content of different tissues and organisms, or of environmental effects (e.g., pH or temperature) on the system. Gas evolution can be measured (thus providing an application for the gas laws) conventionally by displacement of water or, more conveniently and on a smaller scale, with a gas pressure probe. Among the plant tissues to investigate are tubers and bulbs; yeast is also an interesting organism to explore.

One yeast reaction to investigate is alcoholic fermentation, the production of ethanol and carbon dioxide from carbohydrates. Since one of the products is a gas, this reaction, like the decomposition of hydrogen peroxide, is easy to follow by gas evolution. Students can investigate a variety of questions: Is the evolved gas really carbon dioxide? Do all carbohydrates ferment at the same rate? Do all yeasts ferment carbohydrate at the same rate? Is air required for fermentation to occur?

What are the effects of other environmental factors (e.g., pH, temperature, or other substances in solution) on fermentation?

Note that both the decomposition of hydrogen peroxide and fermentation are examples you can use when studying redox reactions:
$2H_2O_2 \rightarrow 2H_2O + O_2$
$_CH_{12}O_6$ (glucose)$\rightarrow 2C_2H_5OH + 2C0_2$

These are both examples of disproportionate reactions, in which one element in an intermediate oxidation state is both oxidant and reductant. To see this, use the usual oxidation numbers for atoms: 0 for elements, -2 for oxygen (except in peroxides), and +1 for hydrogen. In peroxide, each oxygen has an oxidation number of -1. In the products, the two oxygen's in the water have -2 oxidation numbers and those in molecular oxygen, an oxidation number of O. Two of the peroxide oxygen's each gain an electron (are reduced) and two each lose an electron (are oxidized).

For the fermentation reaction, the average oxidation numbers of the carbons in glucose, ethanol, and carbon dioxide are, respectively, 0, -2, and +4. On average, four of the carbons in glucose gain electrons in forming ethanol; these electrons come from the two carbons that lose electrons to form carbon dioxide.

Carbon dioxide and water are a very interesting acid-base system. They can react to form carbonic acid, an organic acid, $0{=}C(OH)_2$. (Or is it an inorganic acid? We usually think of calcite, calcium carbonate, as an inorganic mineral, but where did the carbonate come from?) This reaction and its reverse to form carbon dioxide and water are rather slow. Therefore, when produced in our cells, carbon dioxide and water alone would react only slowly to form carbonic acid (and hence bicarbonate ion, the form in which much of it travels in the bloodstream). When the carbonic acid (bicarbonate) reaches our lungs, it needs to revert to carbon dioxide in order to be excreted from the body. But this reaction is also naturally slow and would not occur in the few seconds the blood spends in the lungs. The consequence is that we would quickly asphyxiate in the product of our own metabolism if there were not some way of speeding up the hydration and dehydration of carbon dioxide.

These reactions are catalyzed by the enzyme carbonic anhydrase in our blood. The uncatalyzed and catalyzed (by the enzyme purchased from a biochemical supplier) reactions are easily studied in aqueous solutions of carbon dioxide (club soda) by adding some base and timing how long it takes to neutralize it (Bell, 1985). The reaction can be followed colorimetrically with an acid-base indicator or with a pH electrode interfaced to a computer.

A study of photosynthesis presents ample opportunities for inquiry that could extend through the entire course as different aspects are investigated, or be introduced as a culminating project. The overall photosynthetic reaction is usually written as

$$6C0_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(aq) + 60_2(g)$$

This is another example of a redox reaction. Have the students prove this for themselves. Note that the role of water as a source of electrons in photosynthesis is another example of the enormous importance of water in biological systems that is often overlooked at the introductory level.

Students can investigate the redox process in an aqueous system containing a water plant or chloroplasts (Chan, 1996; Barcelo and Zapata, 1996; Holman, 1996). Dyes that change color when they are reduced, notably 2,6-dichlorophenol

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TABLE 8.2

Correlations of the NSES to Organic/Biochemical Topics	
STANDARD	ORGANIC/BIOCHEMICAL TOPIC
Inquiry Standard A: Abilities Necessary to do Scientific Inquiry Use technology and math Formulate and revise explanations, models -- ---- **Physical Science Standard B:** Structure of Atoms Structure and Properties of Matter Atoms interact by sharing electrons, outer electrons govern chemical properties Atoms have periodic properties Bonds are formed by electron-sharing Interactions among molecules are determined by their bonding and structure Carbon atoms can bond together in chains, rings, and networks, including polymers Chemical Reactions Chemical reactions occur all around us Chemical reactions release or consume energy Many reactions involve transfer of electrons (oxidation/reduction) Many reactions involve transfer of protons (acid/base) Reaction rates depend on fundamental properties including shape, of the reactants Catalysts control reaction rates, and enzymes are the catalysts in biological systems *Conservation of Energy and Increase in Disorder* Everything (including matter) tends to become less organized with time Interactions of Matter and Energy Waves have energy and can transfer it when they interact with matter Energy of electromagnetic waves comes in packets that depend on wavelength Molecules gain or lose energy in discrete amounts	**All Suggested Investigations Can be Inquiries** Use probeware and computers as suggested Emphasize inductive reasoning and inference from observations, e.g., solubility of sugar **Prequisite to Understanding Bonding** Electron-rich atoms in one molecule are attracted to more positive electron-poor atoms in another Variety of bonding geometries for groups 4, 5, and 6 atoms provides great structural variation Stereochemistry; specificity of enzyme reactions such as salivary amylase; the nonrandom, 3-D shapes of proteins, nucleic acids Wide variation in the R groups attached to functional groups (Note that units in biopolymers are not connected by carbon—carbon bonds.) All reactions from this chapter: fermentation, starch hydrolysis, photosynthesis, metabolism, etc. Photosynthesis, metabolism, including ATP production and use Photosynthesis, fermentation, peroxide decomposition Side groups on proteins and the solubility properties of proteins Hydrolysis of biopolymers, decomposition of peroxide, phenolphthalein decolorization in base Enzymatic hydrolysis of biopolymers (amylase, proteinases) and peroxide decomposition (catalase) Instability of all biopolymers to hydrolysis; energy input required to synthesize biopolymers Photosynthesis Wavelength dependence of photosynthesis Wavelength dependence of photosynthesis
Life Science Standard C: *The Cell* Most cell functions involve chemical reactions Plants carry out photosynthesis	**(See this entire chapter.)** **Photosynthesis**

indophenol (also used as a redox titrant for vitamin C), can be used in colorimetric procedures to follow their interception of electrons (or equivalent) in the redox pathway.

Since CO2 is an acidic oxide, a decrease or increase of its concentration in aqueous solution should lead to changes in the solution pH. Similarly, the dissolved oxygen concentration (or pressure of oxygen over the solution) should change, depending on whether there is a net increase of O2 by photosynthesis or a net decrease of O2 by respiration.

Energy from light is required for photosynthesis. Students can study the effect of different energies of light, that is, colors or wavelengths, using filters on the light source (Physical Science Standard B: interactions of energy and matter).

The list of examples is endless. The references in this chapter are simply starting points. You and your students can scan the journals and technical newsletters that cross your desk or arrive in the school library for more ideas. And your students can develop their own projects based on the questions they have about the systems you are studying or that are mentioned in their texts and other reading. Beginning with the chemical-biological interconnections outlined in this chapter, you can continue to build your repertoire of replacements for some of the traditional inorganic examples and investigations. You will be addressing the fundamental concepts and principles found in the NSES (see Table 8.2), you will add life to your chemistry, and you and your students will have fun.

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CHAPTER NINE

"Grounding" Chemistry with Earth and Space Science

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Jennifer slapped the lab bench. "OK, I got it! He'll never fool me again." She was examining a tray of minerals to identify them by using their characteristic property of cleavage. She had hit the chunks of halite several times. They always broke in smooth-surfaced little cubes. (Students of all ages do like to break up rocks and minerals when given the chance.)

Her brother had apparently exchanged the ingredients in the salt shaker and sugar bowl so often at home that she was afraid to use either one anymore. Now she felt empowered with her useful knowledge. She could tell which was salt and which was not because she knew that halite was a dirty variety of table salt (sodium chloride), a mineral with characteristic cubic cleavage. She was also ready to learn why halite always cleaves in three directions to form cubes. She will have a frame of reference to understand how sodium and chlorine are bonded in a cubic crystal structure, because this connects with powerfully useful knowledge for her—in this case, defeating her brother.

The National Science Education Standards (NSES) call for teaching a core of science knowledge, understandings, and abilities to all students. To accomplish this, we need to identify the many areas of content overlap found in the NSES. Earth and space science can help add a context to chemistry classes, allowing the teacher to address components of both Physical Science Standard B, and Earth and Space Science Standard D.

Many chemical and earth science concepts can be built on the understanding that rocks are made of minerals, and that minerals have definite chemical compositions and crystal structures that give valuable clues to past events. For instance, the alpha proton X-ray spectrometer aboard the Mars rover, Sojourner, is used to understand the chemistry of Martian rocks using spectral analysis, from which the history of Mars can be inferred. People seem to care about what happened on Mars because Mars might be like our planet, and we are naturally interested in ourselves. Is there life there? What can the rocks tell us about possible life on Mars? What can Martian rocks tell us about the evolution of our own planet? Much of the evidence available to us to answer to these questions is based on chemistry. Chemistry is one of the most useful tools of earth and space science research. By introducing students to the connections among past and modem scientific questions, through connecting science disciplines, it is possible to include all of the grades 9-12 content standards in a required set of revised high school science courses.

Using Earth Science to Enhance the Breadth of Chemistry in the Standards
Jennifer's knowledge of the structure and properties of a sodium chloride crystal, the mineral halite, can serve as a simple example of how the Physical Science Standard B can be addressed using earth science content as a context for developing understandings in chemistry across the content standards. For grades 9-12, Standard B (NRC, 1996) calls for teaching the following: Structure of Atoms

Because of the atomic structures of sodium and chlorine, they form ionic bonds in the crystalline structure of halite or table salt. The same holds for all chemical compounds found in minerals.

Structure and Properties of Matter
Predictable chemical composition and crystal structures determine the properties of minerals in Earth's and Mars's rocks. Conversely, the properties of minerals give clues to the chemical composition of the minerals and therefore of the rocks, because rocks are aggregates of minerals. Halite formation usually requires a source of sodium chloride, water for a solvent, and a set of environmental conditions for precipitation from solution. From the chemistry of the rocks, many questions of origins, availability, and uses can be answered.

Chemical Reactions
Predictable compound formations and solutions take place in and on Earth and on Mars, depending on the elements and energy available. The 12 elements that occur in the most abundance in the Earth's crust are the main chemical constituents of the minerals. They are, from the most abundant by weight percentage: oxygen, silicon, aluminum, iron, calcium, magnesium, sodium, potassium, titanium, hydrogen, manganese, and phosphorus (Skinner and Porter, 1995).

Sodium chloride deposits around the planet give a history of locations of salt concentrations and precipitation that can tell us of past environmental conditions in the deposition locale. Human influences can affect compound formations and thus eventually Earth processes such as the hydrologic cycle and groundwater filtration.

Chemical weathering includes the production of carbonic acid by the dissolution of carbon dioxide in water, hydrolysis of potassium feldspar, oxidation of iron, dehydration of minerals such as goethite, and the dissolution of carbonate minerals by carbonic acid. Such weathering affects the distribution of rocks and minerals and thereby the landforms and water bodies that support (or do not support) life on this planet.

Motions and Forces
Atomic forces, gravity, and the kinetic molecular theory all relate to conditions that generate igneous, metamorphic, and sedimentary rocks. Halite is a mineral found in chemical sedimentary environments, where precipitation from solution is possible.

Kinetic molecular theory and gas laws explain many of the variables involved in atmospheric patterns, weather, and climate. Meteorology is one of the sciences included in earth science.

Conservation of Energy and Increase in Disorder
The distribution of matter and energy through interacting Earth systems contributes to creating the quiet sedimentary environments where sedimentary minerals and rocks can be precipitated from solution. Precipitation may result from biochemical reactions (plants in sea water can decrease acidity and cause calcium carbonate to precipitate) or inorganic reactions (cooling water in hot springs can allow opal or calcite to be precipitated).

Interactions of Energy and Matter
Factors contributing to the distribution of matter and energy within and between Earth and space systems include solar fusion releasing solar energy; the creation of Earth materials from stellar fusion, radioactive decay, and gravitational energy acting on Earth materials; heat transfers through convection propelling the Earth's plates; plate movement and position in relation to the equator where solar insolation (incoming solar energy) is greatest; changes of state of water; and movement of water resulting from insolation. All of these factors contribute to the formation of halite.

The example of halite can also be used to address components of the Unifying Concepts and Processes Standard:

Systems, Order, and Organization
Orderly crystal structures result from conditions in hydrological and rock cycle systems.

Form and Function
External forms reflect internal crystallography, which determines the properties and uses of materials (from Earth or Mars). The mining of halite, which sometimes takes place under cities, can be introduced to address some of the learning goals associated with Science and Technology Standard E. Salt usage is relevant to Science in Personal and Social Perspectives Standard F. For centuries, salt has contributed to human survival through the preservation of food. At one point in human history, salt was so important that it became a medium of economic exchange. Salt has also been deadly for living organisms in highly salty water basins like the Great Salt Lake, the Dead Sea, and increasingly the geologically recent Salton Sea in California. The reasons salt is so deadly to life lead into the biochemistry of Life Science Standard C.

The chemistry related to the ionically bonded salt sodium chloride is important to human beings and is therefore an interesting way for students to learn a lot of chemistry-related concepts identified in the content standards. Chemistry can be fascinating.

All of the chemistry cited thus far has been "mined" from the NSES without mentioning the Earth and Space Science Standard D, examples from which follow below. However, all of the above examples are derived from Standard D. The standards allow us to introduce topics and concepts that will perform a double duty: simplifying curriculum planning and teaching.

Your Particular High School Courses
The NSES describe what science content all students should learn in grades 9-12. Considering traditional high school courses and who takes them, there is a gap when it comes to earth and space science in particular. Most students take biology, about half take chemistry, fewer than a quarter take physics, and still fewer even get the chance to study earth and space science. How can course offerings be redesigned so that students are not deprived of the opportunity to take a broadly based science curriculum?

In most situations, the quickest fix is to redesign existing high school science courses, including chemistry. "Reduce" is the first step in modernizing most high school science courses. For chemistry, a comparison of the traditional chemistry course content with Standard B makes the reduction fairly straightforward. The next step is to identify what other content standards can be included in which courses, so that a required combination of courses can be provided by the science department that will, in toto, cover all the fundamental concepts and principles described in the content standards.

Much of the chemistry embedded in the NSES can be taught in conjunction with earth and space science, especially as a context for the useful chemistry involved. Earth scientists consider chemistry one of their "tools." "Turn around is fair play." Chemists can consider earth science a tool for chemistry. Jennifer's interest in the mineral halite is one example of how to bring the two sciences together.

Using an earth science context to teach chemistry is an effective way to introduce matter and energy relationships in interacting and closed systems. Earth science is based largely on interacting systems and subsystems, for example, water-based liquid solutions move, evaporate, sublimate, condense, and percolate. Elements and compounds precipitate out of solution. Energy is transferred and distributed through interacting Earth systems (Physical Science Standard B: Chemical Reactions, Interactions of Matter and Energy). The interacting systems and subsystems of the water cycle and rock cycle are concrete earth science examples that provide a context for learning chemistry.

Each of the content areas in the NSES addresses only one part of the total description and explanation of the natural world. Subject matter taught in isolation does not have as much appeal to the majority of students as subject matter presented in context. It was not by accident that the criteria for selection of the Unifying Concepts and Processes begin with the statement, "The concepts and processes provide connections between and among traditional disciplines."

An Earth Science Context for Chemistry Assessment

There are many opportunities for developing ongoing and culminating assessments (see Chapter 14) in chemistry that can be stated in an earth science context. For instance, the scenario of Jennifer and her mischievous brother could be used for the following assessments:

- Jennifer wants to find out if her brother has switched sugar for salt in the saltshaker. How could she find this out? Include an explanation of the atomic structure and properties of crystalline matter, with halite as your model.
- Devise an analysis procedure that Jennifer could use to differentiate among small white mineral fragments. Explain the structure and properties of matter on which she could base her analysis.
- You have discovered a precipitate in a stream leading to a salmon hatchery (or a public water supply reservoir or in an apparent dry stream bed on Mars).
- Describe (using a hypothetical or real substance) its crystal structure and possible chemical composition related to its
- physical properties. Identify what minerals it could be, using a mineral chart (at the back of most earth science textbooks).
- You think you have found a new mineral (a chemical compound). Explain why and give it a name. What type of planetary environment could have produced this particular mineral? Explain why this could or could not be a mineral found by Sojourner on Mars.

Assessments should be ongoing and require new thinking on the part of the student, leading to enhanced, ongoing learning. Thus, assessment can do double duty for the teacher (assess and teach) and make chemistry more interesting for everyone. Students actually want to discuss answers after creative assessment, if new applications for their thinking are required. They will want to discuss whether there are definite answers possible based on the available chemical evidence (see the History and Nature of Science Standard G).

Earth Science Applications: Unifying Concepts and Processes

Basically, all of chemistry is derived from earth and space science, from the origin of the universe to the evolution of the Earth system. All of the matter-matter and matter-energy interactions address the overlap between chemistry and earth and space science. The following examples identify some chemistry-based earth and space science concepts that could find their way into chemistry classes. Physical Science Standard B has already been discussed, particularly in connection with halite, but all of the examples could be applied in broader contexts than for just one particular mineral. They relate to the other content standards and represent a possible starting point. The first examples address the learning goals of the Unifying Concepts and Processes Standard:

Systems, Order, and Organization

The planet Earth has differentiated layers caused by the characteristics of the elements, their compounds and densities, and sufficient energy to allow for movement. Iron and nickel are concentrated in the core; silicon, aluminum, sodium, and potassium, in the crust. Atmospheric gases, including mainly water vapor, CO_2, and CH_4, escaped by volcanism (Skinner and Porter, 1995). Minerals (compounds and elements) have predictable patterns of order among their elements and are organized in crystallographic systems. The interaction of Earth and space systems involves matter and energy exchanges (e.g., atmospheric systems to hydrologic systems: wind to ocean waves, water vapor to surface water).

Evidence, Models, and Explanation

Spectrographic evidence indicates the chemical composition of rocks on Mars. Red sands on the beaches of Puerto Rico give evidence of oxidation of iron and indicate a source of iron and of oxygen in the region.

The measurement of radioactive decay of elements in minerals, based on known rates of decay and ratios of isotopes present in rocks, gives evidence of ages of events that cannot be recreated for direct analysis. A model of the structure, densities, states of matter, and chemical composition of Earth layers can be constructed from indirect evidence (propagation of seismic waves). Explanations of the evolution of life on Earth can be developed in part on the basis of chemical analysis of organic functions (aerobic or anaerobic) and the geologic evidence of the chemical environments available and necessary to support that life at that time.

Change, Constancy, and Measurement

Geological data, based in part on rock and mineral chemistry, give evidence of constant changes on the planet Earth. For example, granite is made of quartz (SiO_2) and various types of feldspar, including potassium aluminum silicate. Chemical weathering, by hydrolysis, of potassium feldspar produces a clay, kaolinite. Breakup, transport, sorting, and deposition of granite's quartz and clay give evidence of constant change on the planet. Measurement of the specific gravity of minerals is one way to identify their composition.

Evolution and Equilibrium

Evolution of organic populations and their equilibrium within the bounds of their supporting environments and chemical needs (i.e., available oxygen and nitrogen) are evident in the Earth's fossil record.
Evolution and equilibrium of the Earth and its atmosphere are based on the chemistry of the available matter and its interactions with the available energy. A change in either alters the equilibrium; for example, a reduction in the insolation available can change the amount of oxygen and carbon dioxide in the atmosphere and destroy the extant equilibrium.

Form and Function

The external form of a mineral results from its internal chemical (crystallographic) structure, which is controlled by the bonding possible. External forms and internal chemistry determine properties and uses.

For example, diamonds have strong, three-dimensional, covalent bonds among the carbon atoms, each atom sharing its four outer electrons with four other carbon atoms. Graphite has two-dimensional covalent bonding with weak van der Waals bonding between sheets. Diamonds are hard; graphite sheets easily, making it a good lubricant.

Inquiry Standard A

Abilities To Do Scientific Inquiry
The interactions of energy and matter, and the conservation of matter, can be explored in the context of disposal and/or recovery of chemical wastes. Many years after disposal, the wastes may cause a variety of problems, some of which may be related to the formation of new substances. What are the properties of these new compounds, and how could they be neutralized, diluted or recovered?

Understanding about Scientific Inquiry
The use of direct lines of evidence in scientific inquiry is relatively easy to experience in traditional chemistry. Lines of evidence that use chemistry for indirect evidence of past events (e.g., the age of the Earth, of fossils) or for developing models for systems that are not directly accessible (structure of the Earth) give a broader picture of scientific rules of evidence.

Earth and Space Science Standard D
Earth and Space Science Standard D has categorized fundamental concepts and principles in four areas. Each area contains learning goals of relevance to chemistry teachers.

Energy in the Earth System
The sun, the radioactive decay of isotopes, and the gravitational energy of formation provide the energy that moves throughout the interacting Earth and space systems, moving water, rock, mantle and core material, and gases. The chemical composition and interactions of all matter determine the properties of the building blocks for Earth and the life it supports.

Geochemical Cycles
The amount of matter on the Earth is finite (except for trapped meteorites!) and moves, powered by solar and Earth energy sources, among reservoirs (the solid Earth, the oceans, the atmosphere, and organisms). As it cycles among these reservoirs, it recombines as different compounds and in different states of matter. The hydrologic-, atmospheric-, rock-, and carbon and nitrogen cycles, and their intersections, are systems with subsystems that provide for the movement of matter within and among Earth and space reservoirs.

Origin and Evolution of the Earth System
The matter and energy in the Earth system are derived from the sun. Understanding solar fusion and the creation of the elements, the periodic arrangement of the elements, and their related chemical properties is grounded in the field of chemistry. Movement of Earth and space systems involving solar matter and energy is the basis for the evolution of the planet. Our understanding of relative time for geologic events and evolution is based on chemistry (nuclear reactions, rates of radioactive decay of isotopes, release and capture of gases in the atmosphere, regulation of global temperatures by the water, and carbon cycles).

Origin and Evolution of the Universe
A consideration of the physical origin of the universe centers on the nature of the origin of increasingly complex forms of matter and of sources of energy, especially nuclear and gravitational energy. The behavior of interacting systems of matter and energy characterizes the evolution of the universe.

Science and Technology Standard E
The learning goals in Science and Technology Standard E can be addressed using earth science and chemistry examples. Evidence for the chemistry of the Earth and space has resulted from the development and use of a wide range of technologies: Earth- and satellite-based telescopes, spectrometers, extraterrestrial rovers, seismometers, gyroscopes, global positioning systems, etc.).

Science also contributes to Earth, space, and chemical exploration technologies: the remote-controlled bathoscape, technologies for space exploration and reentry systems, and the alpha-proton X-ray spectrometer.

Science in Personal and Social Perspectives Standard F

Population Growth
The synthesis of ammonia from nitrogen and hydrogen via the Haber-Bosch process in the early 1900s made synthetic nitrogen fertilizers widely available (Smil, 1977). This has increased food production and, hence, has sustained growth in human populations. However, the synthetic nitrogen-based fertilizers have increased and extended food production into geologically unsuitable land. Chemical fertilizers are adversely affecting the groundwater and surface water supply in many locations.

There are limitations on the carrying capacity of Earth (biogeochemical) systems. Geologic evidence indicates that population extinctions have occurred throughout geologic history. In most cases, environmental support system failures and limits on carrying capacity seem to have been the causes. The redistribution, and extensive use, of surface water supplies increases the suitability of land for human habitation. It also puts an increasing load on the natural Earth systems (atmospheric, soil and rock distribution, hydrologic, biologic, etc.).

Natural Resources
Fossil fuels provide the nonrenewable energy sources powering the developed countries. Extensive geologic considerations are involved in their origins, distribution, discovery, and recovery. The chemistry of the fossil fuels and the by-products of their combustion are of great importance to humans and their Earth environment.

Inorganic minerals provide the ores, metallic and nonmetallic, on which human culture increasingly depends. Understanding the origins, concentrations, locations, development, and recovery of metallic and nonmetallic ores is rooted in the geosciences. Their chemistry is entwined with their origins, recovery, and uses.

Soils provide, or do not provide, the mineral nutrients necessary for plant growth. Animals depend on a food chain based on plants. Therefore, the chemistry of soils, derived from rocks and sometimes bioorganic contributors, determines the extent to which life can survive on Earth.

Life on Earth depends on water resources and chemistry, the polarity of the water molecule, the states of matter in which water can exist on the planet, the hydrologic cycle, and the patterns of movement of groundwater and surface water. Earth systems are being strained by human use and manipulation of nonsaline water.

Environmental Quality
Chemistry and earth science are intrinsic areas of research and knowledge related to the quality of the atmosphere, the generation of soils, the control of the hydrologic cycle, and the disposal of waste and recycling of nutrients. The chemical cycles of the Earth support human life and are affected by human use and interventions.

Natural and Human-Induced Hazards
Hazardous changes in geochemical Earth systems may occur naturally, or as a result of human activities; for example, chemistry (and physics) can be explored in the winds of a hurricane. Plate movements, which generate earthquakes and volcanism, are believed to be powered by convection in the Earth's mantle, which is heated by radioactive decay of isotopes.

Science and Technology in Local, National, and Global Challenges
Many challenges facing humanity today can only be addressed through the partnership of chemistry and the earth sciences. These challenges include disposal of chemical wastes that are seeping into groundwater supplies, urban smog generation and atmospheric patterns, fossil fuel burning for electrical generation, and ozone depletion and UV penetration. (Ensuring that students meet learning goals related to this component of Standard F, which requires coordination among chemistry and the earth sciences, may provide the most important reason for all students to gain the scientific literacy envisioned in the NSES.)

The research techniques of chemistry and earth and space science combined can give a more complete picture of the rules of evidence of science and how evidence can be direct or indirect, confirming, corroborative, or contradictory. The limitations of evidence, the need for ongoing reconsideration based on increasing evidence, and the research challenges in each subject matter area all complement and extend the student's understanding of the nature and history of science.

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CHAPTER TEN

Science and Technology Literacy and the Standards

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With the release of the National Science Education Standards (NSES), teachers, school systems, curriculum developers, assessment specialists, and teacher educators have guidelines for science and technology content, processes, assessment, and professional development. There is a science and technology content standard for each of the three grade bands (K-4, 5-8, and 9-12). Collectively, they define what students should know and be able to do related to technology as it relates to science, by the time they graduate. They do not represent a complete set of national standards for technology education.

By the time students reach 9th grade, they are expected to have had an opportunity to understand principles of technological design, evaluate the effectiveness of technology, use and/or create simple technology to solve problems, and explain the differences between the nature and purposes of technology on the one hand and science on the other. In grades 9-12, students are expected to demonstrate "abilities of technological design" and "understandings about science and technology" at a much more sophisticated level (NRC, 1996).

In terms of technological abilities, students are expected to design and implement technological solutions to problems from a variety of different contexts (home, community, region, nation, world) and "meet [design] criteria while addressing conflicting constraints." Students might be expected to develop such skills as reading and drawing simple blueprints and circuit diagrams, working with a variety of materials to construct equipment, and using computer software. They should be able to evaluate design solutions and then modify them as appropriate. Most important, students must be able to communicate their results to each other and to teachers, both orally and in writing.

In terms of technological understandings, students are expected to recognize that the natures of science knowledge and technological knowledge are different, yet they interact synergistically. They should learn about the importance of the contributions of both to problem solving, and the risks and benefits associated with the implementation of specific technological solutions.

Elaboration of the Content Standard
For each standard at each grade level, there is an explanatory guide that delineates fundamental concepts and principles related to the standard. The guides to the science and technology standards, while useful in a general informational sense, are not specific on how to help students achieve the required learning goals in terms of either knowledge or skills.

Curriculum developers and teachers who look to the NSES for guidance on how to design curricula that address the science and technology standards are given some help in the form of introductory vignettes that illustrate what an appropriate technology education experience should look like in the classroom. These suggested experiences are helpful to teachers by providing exemplars, but they are limited in scope. Teachers need more help if they are to develop curricula that are designed to incorporate the NSES learning goals.

Creating a Technology-Rich Curriculum
There are other resources to help educators develop a technology-rich curriculum. Over the past several years, the U.S. Departments of Education and Labor have awarded grants to various organizations, including the American Chemical Society (ACS), to develop a series of workplace competencies (knowledge and skills) that relate to the job functions of workers in some 22 different industries. A number of these so-called skills standards or voluntary industry standards relate to science- and technology-based industries, for example, the chemical process industries (CPI), medical technology laboratories, automobile manufacture, and biotechnology-related industries.

Not surprisingly, the ACS was asked to develop the skills standards for technicians (both laboratory technicians and plant operators) in the chemical process industries. The recent ACS final report on this project, *Foundations for Excellence in the Chemical Process Industries,* lists specific critical job functions for CPI technicians in terms of performance objectives (Hofstader and Chapman, 1997).
The ACS Education Division is using this report and other skills standards documents, most notably skills standards related to the bioscience industry (EDC, 1995), to inform the development of a new science and technology high school curriculum, *Science in a Technical World (Science Technology, Knowledge and Skills).*

Science in a Technical World is a two-year tech-prep program for students in 11th and 12th grades. It consists of a series of modules, each designed to take about five weeks of instruction, which focus on the types of problems that technicians face every day. Each module deals with a central problem from a different industry. Working through each module, students investigate how technicians in the industry use technology to address production problems. Students do this through hands-on laboratory activities, and video and CD-ROM components that provide a plant tour, a virtual workplace, and embedded performance assessment.
Modules currently under development relate to the carbonated beverage industry, wastewater treatment, biotechnology, petroleum exploration, petroleum cracking, paint manufacture, the plastics industry, and the baking industry. An additional six modules are planned. The first-year materials are being field tested in the 1997-1998 school year.

The *Science in a Technical World* program is standards-based in that the modules are "mapped" against all the NSES, not just Science and Technology Standard E, as well as the benchmarks for science literacy produced by the American Association for the Advancement of Science (AAAS, 1993). The modules also incorporate a number of the skills standards for both the chemical process industries and the bioscience industry.

Although some of the learning goals of the *Science in a Technical World* modules are common to most high school science curricula, many of the standards addressed in *Science in a Technical World* are specific to technology courses and are work-place oriented. As they are developed, the modules are not only mapped against these standards, but may be modified to include previously excluded standards if they are relevant to the work of the technician in each specific industry. The final six industries will be selected to broaden the range of learning goals to address more of the national science content standards. A more specific illustration of how *Science in a Technical World* modules relate to the NSES Science and Technology Standard E for grades 9-12 is shown in Tables 10.1 and 10.2. The first addresses that section of the standard related to technological design; the second looks at technological understandings.

Equipment Management in Science in a Technical World
Not only does *Science in a Technical World* involve solving technology-based problems, but students will have an opportunity to use forms of technology that they probably would not use in a traditional science class. This use may be "actual," as in the laboratory, or "virtual," using the computer. To help teachers deal with this, the *Science in a Technical World* teacher's version gives instructions for how to procure, build, and manage the equipment used in each module.

TABLE 10.1
Technological Design and the *Science in a Technical World* Carbonated Beverage Module

NSES STANDARD E: ALL STUDENTS SHOULD DEVELOP ABILITIES OF TECHNOLOGICAL DESIGN	ACTIVITIES IN THE SCITEKS MODULE
Identify a problem or design an opportunity	Students identify what could be wrong with a carbonated beverage that is "off-spec."
Propose designs and choose between alternative solutions	Students propose a procedure for determining what is wrong with the off-spec beverage. They can follow a variety of pathways to find the solution to the problem.
Implement a proposed solution.	Students run a series of laboratory tests on the sample of off-spec soda to collect data on what might be the problem with it.
Evaluate the solution and its consequences	Students analyze their soda data to determine what is wrong with the soda. Data are compared to company specifications for each raw material in the soda, as well as to specifications for the soda itself. Students suggest ways of rectifying the problem during manufacturing.
Communicate the problem, process, and solution Source: NRC, 1996.	Students communicate the problem, process, and solution to a representative from quality control in a local bottling industry.

Equipment includes an activated sludge tank, student-built and -calibrated hydrometers, simulated laminar flow hoods, chambers and devices for polymer testing, and so on. Field test teachers for the program will provide feedback on the management of equipment, which will later be incorporated into the final versions of the curriculum.

Tracking Content
Science in a Technical World is a technology-rich curriculum at the high school level that is using the NSES, the benchmarks, and the national skills standards to help define content. It is difficult enough to keep track of one set of standards; keeping track of several certainly complicates module development. As *Science in a Technical World* modules are produced, grids are kept to track the learning goals (knowledge and skills) for each module. These grids can then be used to relate the learning goals of the module to any of the sets of standards. These grids are evolving documents; they may change significantly after the first field test.

Of course, the total *Science in a Technical World* program of 14 modules will be taught over a two-year period. All of the NSES content standards will not be addressed over that two-year period. However, it will be clear to users of the curriculum exactly what the relationships between *Science in a Technical World* and the NSES actually are.

TABLE 10.2 **Understandings about Science and Technology and any *Science in a Technical World* Module**	
NSES STANDARD E: ALL STUDENTS SHOULD DEVELOP UNDERSTANDINGS ABOUT SCIENCE AND TECHNOLOGY	ACTIVITIES IN THE *SCIENCE IN A TECHNICAL WORLD* MODULES
Scientists in different disciplines ask different questions, use different methods, and accept different types of evidence. Many scientific investigations are [interdisciplinary].	*Science in a Technical World* is interdisciplinary. Students ask questions related to biology in some modules; chemistry and the earth sciences in others. Investigation protocols vary, as do data sets, analysis · methods, and types of conclusions.
Science often advances with the introduction of new technologies. Solving technological problems often results in new scientific knowledge.	Students use their science knowledge to solve technological problems; as they solve the problem they must acquire new (to them) scientific knowledge.
Creativity, imagination, and a good knowledge base are all required in the work of science and engineering.	Students are encouraged to draw on the **CD-ROM** (encyclopedia and glossary), industry contacts, the Internet, prior knowledge, and personal creativity to solve the central problem of each module.
Science and technology are pursued for different purposes. Scientific inquiry is driven by the desire to understand the natural world, and technological design is driven by the need to meet human needs and solve human problems.	All *Science in a Technical World* modules involve the solving of technology-based problems. The focus problem for each module deals with the practical nature of what technicians actually do in industries, meeting a variety of human needs.
Technological knowledge is often not made public because of patents and the financial potential of the idea or invention. Scientific knowledge is made public through presentations at professional meetings and publications in scientific journals. Source: NRC, 1996.	In many of the *Science in a Technical World* modules, students deal with products and techniques that simulate what could be considered proprietary knowledge within a particular industry.

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CHAPTER ELEVEN

Science in Personal and Social Perspectives and ChemCom

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Included in the National Science Education Standards (NSES) is a content standard (F) on science in personal and social perspectives, which states (NRC, 1996):

As a result of activities in grades 9-12, all students should develop understanding of
- personal and community health,
- population growth,
- natural resources,
- environmental quality,
- natural and human-induced hazards, and
- science and technology in local, national, and global challenges.

This chapter focuses on the fourth bulleted item, the personal and social perspectives on environmental quality in terms of the coverage and applications found in the third edition of *ChemCom: Chemistry in the Community*. The environmental quality section of the standard—the fundamental concepts and principles to be addressed on this topic—includes the processes whereby humans interact with physical and chemical ecosystems (the atmosphere, soil, the water cycle, waste disposal, and nutrient recycling) as well as the many factors (natural and human, technological and socioeconomic) that influence environmental quality.

Some of the concepts and principles to be addressed link more directly to biology or earth sciences than to chemistry. However, there are many opportunities in a chemistry class to introduce some of these topics, the task being much simpler for a *ChemCom* teacher than a teacher of a more traditional science course, because *ChemCom* is organized around a number of societal issues, many of which address environmental quality.

Two major areas of environmental concern are air quality and water quality, both discussed in detail in *ChemCom* (see next page). However, first let us consider a few broader issues related to environmental quality that have the pedagogical value of debunking myths or errors by using chemical principles and data.

Some Broader Issues

It is important for students and teachers to recognize and appreciate fully that among the most significant actions taken to address air and water quality were the passing of the Clean Air and the Clean Water Acts by Congress in the 1970s, during a period of emerging environmental consciousness, and their renewal in the 1990s. It is difficult to overstate the enormous impact that these acts have had on improving substantially the quality of the water we drink and the air we breathe. Clearly, they have made a difference to public health and the quality of our lives. Unfortunately, many students erroneously think that air and water quality in the United States are deteriorating. Students need to be disabused of this outlook and learn to appreciate how much improvement has been and continues to be made in air and water quality.

Many students incorrectly assume a priori that the vast majority of air and water pollutants are from human sources. Humans undoubtedly have had an impact on environmental quality, sometimes negative. But the scope of this impact needs to be put into the context of the magnitude of pollution from natural sources. Students need to learn to differentiate between the magnitudes of air and water pollutants created by natural sources and those created by human activities. The relevant data need to be presented so that accurate comparisons can be made and valid conclusions can be drawn.

Students need to recognize and interpret a striking natural irony: The *major* air pollutants (CO_2, CO, O3, NO_x, and SO_x) are only *minor* components of the atmosphere. The impact of these pollutants on our health and our surroundings far exceeds their atmospheric concentrations in comparison to the overwhelming abundance of nitrogen and oxygen. Exploring the impact of pollutants on the environment provides many opportunities to study a host of basic chemical principles.

Balancing equations is part of any chemistry course, a way of emphasizing the fundamental nature of the conservation of matter (and atoms). It is not merely a convenient way to inventory atoms; it is the way nature works. A corollary to be stressed is that "Molecules are transient; atoms are forever" (at least under normal chemical conditions). Part of the beauty and the intrigue of chemistry lies in understanding the many transformations that molecules undergo as atoms are tugged into new and different arrangements, that is, as they form different compounds.

Students need to realize that, after reacting, the same atoms are there, just in different combinations. The carbon and oxygen atoms exhaled as CO_2 by John Dalton, Linus Pauling, or Michael Jordan could be the very ones that are incorporated into a sugar or fat molecule in my body or in that of any other person. Atoms are constantly being recycled.
Pollutants have sometimes been called "atoms that are out of place." They are atoms combined to form compounds that challenge a "normal" chemical system to react in order to restore balance. The pollutants raise the entropy of the operations as well as the cost, which is sometimes substantial, to return the system to its non-polluted state.

At times, technology, including chemical industrial technology, has contributed to the degradation of environmental quality by emission of air and water pollutants. However, technology is Janus-like, creating environmental problems on the one hand and, on the other, providing the means to rectify these problems. The methods used to raise the quality of air and water during the past two decades are the direct result of technological improvements and the desire to seek such changes. Better scrubbers for smokestacks, substitutes for lead in gasoline, oxygenated fuels to reduce tropospheric ozone and photochemical smog, automobile catalytic converters, and the emerging "green chemistry" movement all exemplify the development and application of technologies in response to environmental assaults.

Creating appropriate environmental policy and implementing it require individuals who understand complex science as well as issues of environmental management and politics. In such matters, the science is often exceedingly complex, possibly even contradictory, and not easily given to credible simplifying assumptions. On occasion, policy makers, who are generally not technically trained, fail to appreciate the difficulties of establishing unambiguously the valid science necessary to create legitimate policies and to make decisions based on such policies. And, scientists, too, sometimes fail to grasp the subtleties associated with policy making. The recent congressional debate about airborne pollutant particulate size and health effects exemplifies the complexities and nuances at the intersection of science and public policy.

The ChemCom Units

ChemCom addresses directly many of the NSES Standard F: Environmental Quality concepts and principles by putting science in personal and social perspectives into units on water, resources, petroleum, nuclear issues, and air. The units explore the issues through laboratory activities; decision-making exercises involving role-playing, cooperative learning, and student library research; and more traditional mathematics-based exercises. Each unit ends with a special decision-making activity called "Putting It All Together," which explicitly involves students in using their chemistry knowledge to address the societal and personal issues that drive each unit.

Water

The entire water unit explores both the consequences and the reasons for a fish kill in the Snake River, and it even addresses the issue of "who pays to redress the problem?" In exploring why the fish died, students learn about solution chemistry, heavy ion and other ion contamination, dissolved oxygen, and biochemical oxygen. The issues of quantity and quality of water for personal use are taken up in this unit. This gives students the opportunity to discuss direct and indirect water use as well as personal water use in the context of the limited fresh water on planet Earth. (Although about 75% of the Earth's surface is covered with water, less than 4% is fresh water.) Even the "fresh" water we use must first be pretreated and purified to make it potable. Much of the high rate of infant mortality in non-developed countries can be traced to impure water.

Resources

The part we play individually and collectively in resource management is discussed in this unit within the context of a range of resources, most of which are nonrenewable. The fact that atoms can be made to enter into new and different combinations with other atoms is central to the concept of mineral recycling. This is described with reference to the recovery of aluminum from beverage cans, rather than mining and processing aluminum ore to supply new cans. Conservation of minerals, a companion concept to recycling, is a personal choice with significant societal implications when done collectively.

Students explore the actions of their own school in recycling, reuse, and replacement of resources. They consider what actions the school could take to recycle materials. They realize that discarding materials does not get rid of them; it merely puts them out of sight. Their atoms remain as pollutants, ultimately to be reworked into other chemical combinations.

Students also realize that the global distribution of natural minerals resulted from prehistoric chemical processes that now have enormous geopolitical ramifications. Vital minerals are not distributed uniformly in the lithosphere, thus creating "have" and "have not" nations as metal sources. On a personal level, we use metals directly or alloyed in a variety of products; more than two dozen different kinds of metal ions are essential to our biochemical makeup and well-being.

Petroleum

Petroleum is a resource that has profound personal and societal implications. We use it as a fuel to cook, to drive., and to heat our residences; we also use it to make a wide range of synthetic materials, many of which we use on a daily basis. We may not have enough petroleum to last even through the lifetime of our students unless appropriate alternative technologies are developed to replace petroleum as a fuel and as a chemical feedstock. The uncertainty of how finite this natural resource is creates a vulnerability leading to international political and economic tensions among its suppliers and users. The final exercise in this unit confronts the specter and consequences of a severe curtailment of oil supplies.

Nuclear Issues

Students learn that nuclear radiation is a natural consequence of the radioactive decay of atoms found in us and in our surroundings. Each student can calculate the personal radiation dose a person receives annually and compare this dosage with radiation levels that cause tissue damage. One particular source of environmental background radiation in some homes is that emitted by radon-222, a natural product of uranium-238 decay.

Students explore the production of electricity using nuclear fission as a fuel. They recognize this as a process that produces no greenhouse gases, such as those generated by burning fossil fuels, but that comes with its own environmental hazards. Of particular concern is the safe storage of high-level radioactive wastes, the by-products of nuclear energy or nuclear weapons production.

Air

We need air in order to stay alive, regardless of where we are. Its quality affects us as individuals and as societies. Yet we generally are inattentive to the quality of the air we breathe unless it becomes poor enough to cause respiratory problems.

An entire section of the air unit investigates the extent of human impact on the air we breathe. This section compares air pollutants worldwide from both natural and human sources. The coverage of indoor air quality is unique to *ChemCom*. It explores the nature of indoor air quality and selected indoor air pollutants. The unintended ramifications of technology applied to refrigeration by the use of chlorofluorocarbons (CFCs) and their role in stratospheric ozone depletion are also discussed in this unit (C.8) Technology has responded by creating CFC replacements designed to decrease the stratospheric ultraviolet radiative rupture of C-C1 bonds.

A cautionary note: The chemical principles presented in *ChemCom* are purposefully introduced on a need-to-know basis as they arise within the framework of dealing with a technological issue of societal importance, such as environmental quality. In *ChemCom*, principles are not inserted simply because other texts cover the material at a particular point.

Thus, it is important to resist the natural tendency to "overteach" a given concept or principle in *ChemCom* (i.e., present far more material in greater depth than is needed to understand a particular issue at that point). The maxim that teaching is the art of uncovering material (not merely covering it) applies here, as does the principle enunciated in the NSES that "less is more."

You are encouraged to review the *ChemCom* units to explore further their coverage and applications of the concepts and principles described in Standard F. In particular, personal and community health, natural resources, natural and human-induced hazards, and science and technology in local, national, and global challenges are addressed in *ChemCom*. In addition to the units mentioned above, the topics of food, personal chemistry and choices, and industry are explicitly discussed in the national standards. Even if you are not using *ChemCom* as your textbook, you will find it to be an invaluable resource to address a very wide range of personal and social issues related to science.

Some Sample Activities

The following three activities are taken from the third edition of *ChemCom* (edited by Patricia J. Smith, formerly of the U.S. Air Force Academy High School). *Autos and Smog* illustrates a typical decision-making activity found in the book. The emphasis is on the interpretation of graphical data, which naturally ties the activity to Inquiry Standard A as well as to Standard F.

You Decide: Autos and Smog

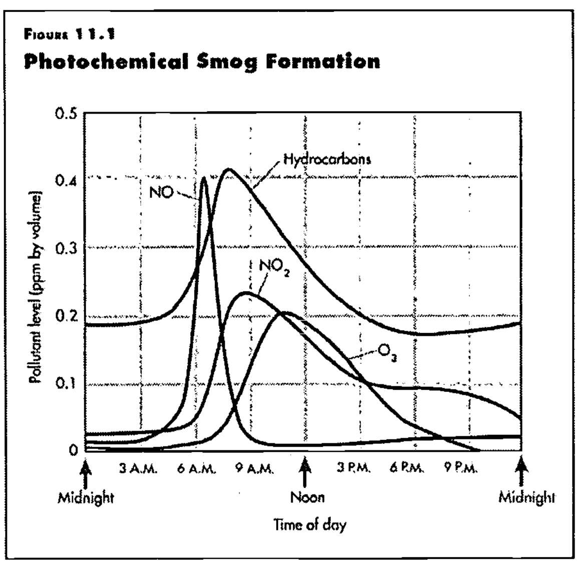
Use data in Figure 11.1 to answer these questions:

1. Between what hours do the concentrations of nitrogen oxides and hydrocarbons peak? Account for this fact in terms of automobile traffic patterns.

2. Give two reasons that a given pollutant may decrease in concentration over several hours.

3. The concentration maximum for NO_2 occurs at the same time as the concentration minimum of NO. Explain this phenomenon.

4. Although ozone is necessary in the stratosphere to protect us from ultraviolet light on the surface of the Earth, it is a major component of photochemical smog.



- Determine from Figure 11.1 which chemicals, or species, are at minimum concentrations when O_3 is at maximum concentration.
- What does this suggest about the production of O_3 in polluted tropospheric air?

Figure 11.1

Teacher Demonstration: The Electrostatic Precipitator

Materials

1 10-mL glass graduated cylinder
18 gauge bare copper wire (exact gauge is not critical)
1 1-hole rubber stopper to fit the graduated cylinder
wire cutters
transparent tape
Tesla coil
source of smoke
Safety

Teacher and students should wear goggles. Be aware of electric hazard due to high voltage. Keep the Tesla coil unplugged until ready for use and unplug immediately after use.

Procedures

1. Assemble the apparatus as shown in Figure 11.2

2. Insert the rubber stopper in a clean, dry graduated cylinder.

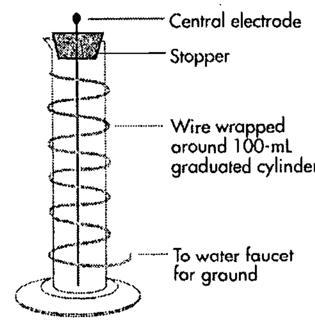
3. Wrap several turns of wire around the outside of the cylinder. Make a loop at the bottom end of the wire. Attach a longer piece of copper wire that can be wrapped around a water faucet to create a ground. Be sure that the water supply line is metallic.

4. Cut a piece of wire about 4 cm longer than the depth the cylinder and make a small loop on one end. Insert wire into the graduated cylinder through the stopper with the loop at the top. This wire should not touch the sides of the cylinder.

5. Remove the wire-stopper assembly, and ignite a small piece of heavy cardboard. Drop the burning cardboard into the cylinder and replace the wire-stopper assembly. (Again, be careful not to touch the sides of cylinder.)

6. Plug in and turn up the Tesla coil.

Figure 11.2
The Electrostatic Precipitator



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7. Hold the Tesla coil as close as possible to the central wire in the cylinder, and allow a spark to jump to the top of the central wire. Exercise extreme care with the Tesla coil. Smoke should clear almost immediately. If this demonstration is performed against a dark background, it will be more visible.

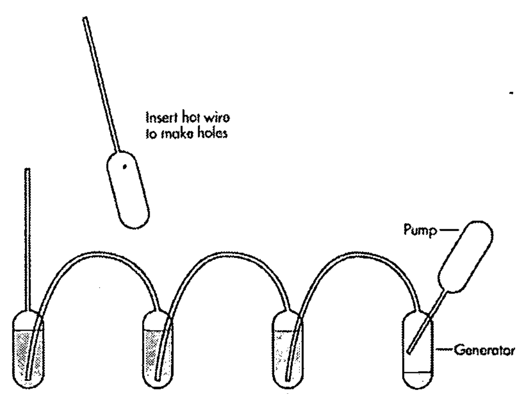
8. Disassemble the apparatus and clean. The cylinder must be clean and dry before it can be used again.

Student Laboratory: Microscale Wet Scrubber
This activity demonstrates the wet-scrubbing process. The pollutant sulfur dioxide is produced by mixing Na_2SO_3 and H_2SO_4.

Materials (for a class of 24 working in pairs)
60 Beral pipets
12 24-well plates
24 50-mL beakers
12 burners
60-cm 16-18 gauge wire, cut in 5-cm pieces
12 tongs
12 scissors
10-mL universal indicator
20 mL 0.5 M Na_2SO_3 (7.96 g Na_2SO_3/100 mL solution)
20 mL 2.0 M H_2SO_4 (11.2 mL conc. H_2SO_4/100 mL solution)

Safety
Students should wear goggles and aprons throughout the laboratory activity.

Figure 11.3



Procedures

1. Hold the wire in a flame with tongs and use the hot wire to make a small hole in the base of the stems of four of the five Beral pipets, as shown in Figure 11.3. The diameter of the hole should be slightly smaller than that of the pipet stem

2. Make a diagonal cut near the ends of the stems of three of the four pipets with holes. Remove one-half of the stem of the pipet without a hole, using a diagonal cut.

3. Label the pipets 1-5, and fill as follows: No. 5 (uncut with hole), No. 4 and No. 3 (cut with holes)—half-full of distilled water plus two drops of universal indicator. The color of the liquid in all three pipets should be green. No. 2 (cut with hole) is empty.

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4. Connect the pipets as shown in Figure 11.3. The inserted stems should reach the bottom of the filled pipet bulbs.

5. Add 2 drops 0.5 M Na_2SO_3 and 4 drops 2.0 M H_2SO4 through the hole in pipet no. 2. *Without releasing the bulb, remove the pump.* (If you allow the pipet to expand before removing it, all the reagents will be drawn back into the pump.) Gas should bubble through the distilled water, carrying the pollutants with it.

6. Reinsert the expanded pipet into the generator and pump gently four times. Record any color changes.

7. Estimate the pH of the contents of the pipets.

8. Dispose of the contents of the pipets into a beaker provided by your teacher.

9. Wash your hands before leaving the laboratory.

Graphing: More Than Just Following Directions

Finally, the following graphing exercise was adapted from the water unit by Lucy Eubanks of Clemson University. It illustrates the use of graphed data to discover regularities and patterns, and it encourages students to use their previous graphing experience and knowledge to generate a graph and consequently interpret the data provided. This activity should take 1-1.5 class periods to complete.

Students are divided into groups of four or five, and each group is given a data table that contains three pieces of information about the water quality of the Snake River in Riverwood. Each student will generate a graph to represent the information in the data table (Table 11.1). Because three pieces of information are given, students will need to spend time deciding how to graph the information. Encourage them to think of ways to graph that will lead to clear and accurate interpretation of the data. You may limit students to preparing a single graph or allow them to generate two graphs. Stress that students must use only one side of the graph paper for the graph(s).

Student Instructions

Data table 11.1 shows the relationship between the month of the year, the average water temperature, and the average dissolved oxygen levels in the Snake River at Riverwood.

1. Each member of your group will prepare a graph of these data. Make independent decisions about the type of graph you wish to prepare, being sure to label your axes clearly and to give your graph a descriptive title. You may only use one side of your graph paper.

2. Compare and discuss the graphs drawn within your group. What are the advantages and/or disadvantages of each type of graph for conveying the information in the table?

3. After discussion has been completed, your group recorder will prepare the group report, which should address two items:

- Which graph, from those prepared in your group, did you find best conveyed the information in the table? Why did you choose it?
- Would the dissolved oxygen content for the Snake River water vary with the time of day? Make a prediction and justify your reasoning.

Expected Results

Students may represent their data as line graphs, bar graphs, pie graphs, or a combination of all three. Several examples of possible graphs are given in Figure 11.4. Some students can be very creative in graph construction and interpretation. This will only add to the general discussion of graphing techniques and the cardinal rules of graphing.

Discussion

Each group will share its report with the rest of the class. A final wrap-up should include the basic rules of graphing (see below). We recommend that the graphing rules be discussed after the activity is completed. Because this is the first graphing exercise in the *ChemCom* textbook, students must rely on their previous graphing skills to draw the graph(s).

TABLE 11.1

Relationship Between Month of Year, Water Temperature, and Dissolved Oxygen Levels in the Snake River

MONTH	WATER TEMPERATURE (°C)	DISSOLVED OXYGEN (PPM)
January	2	12.7
February	3	12.5
March	7	11.0
April	8	10.6
May	9	10.4
June	11	9.8
July	19	9.2
August	20	9.2
September	19	9.2
October	11	10.6
November	7	11.0
December	7	11.0

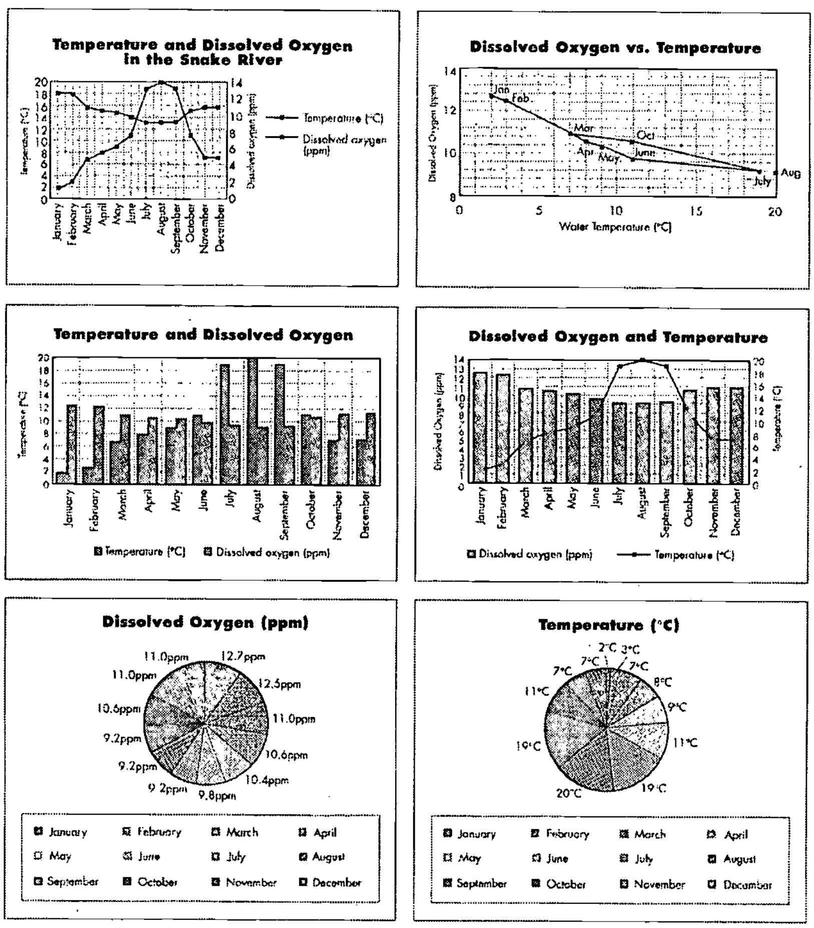
The purpose of this activity is for students to see for themselves the importance of accurately graphing data and using standard graphing rules.

Graphing Rules

- Choose the scale so the graph becomes large enough to fill most of the available space on the graph paper.
- Each regularly spaced division on the graph paper should equal some convenient, constant value. In general, each interval between graph paper lines should have a value easily divided "by the eye" such as 1, 2, 5, or 10, rather than a value such as 6, 7, 9, 14.
- An axis scale does not need to start at "zero," particularly if the plotted values cluster in a narrow range not near zero. For example, if all values to be plotted on the x axis are between 50 and 60, the x axis scale can begin at 50 and end at 60.
- Label each axis with the quantity and unit being graphed. For example, a scale might be labeled "Temperature (°C)."

FIGURE 11.4

Possible Graphs



- Plot each point. If you plot more than one curve on the same graph, distinguish each set of points by using a different color or geometric shape, such as ◊ or Δ

Although this activity is from the first *ChemCom* unit, there are several other graphing activities in the *ChemCom* text, as well as other chemistry textbooks, that could be handled in the same manner. This type of activity involves the students directly in decision making and encourages them to discuss the advantages and disadvantages of choosing different types of graphs to represent information. They leave the classroom with an "ownership" of the graphing concept and a justification of proper graphing techniques. When teachers simply give the complete directions, students do little thinking to produce the final product.

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CHAPTER TWELVE

The Standards and the History and Nature of Science

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The National Science Education Standards (NSES) suggest that as a result of activities in grades 9-12, all students should develop an understanding of science as a human endeavor, the nature of scientific knowledge, and historical perspectives (Content Standard G, NRC, 1996).

While each of the areas cited above overlaps with the other, in this chapter each will be treated separately in order to clarify and give examples that relate specifically. Furthermore, the examples given will address chemistry in particular. From the eighteenth century onward, scientists have recognized chemistry as "the central science," the one that unifies and relates to all other sciences. As understanding of matter– and particularly the nature of atoms and molecules– grew, it soon became apparent that the molecular view of matter was the most powerful tool at the disposal of anyone who sought to understand the processes of nature.

Science as a Human Endeavor

Early scientists often pursued their investigations as a hobby. For example, Robert Boyle and Henry Cavendish were driven in their scientific pursuits by a burning curiosity about the nature of matter and energy and spent their considerable fortunes in this pursuit. Science was studied in schools as part of "natural philosophy," as exemplified by the publication of the British *Philosophical Magazine* from 1797 to the present day as the journal in which to publish new scientific results. Among its many noted contributors were Alessandro Volta, Humphry Davy, and Michael Faraday.

As the scientific endeavor grew in scope, particularly after 1950, doing science was no longer the domain of curious individuals but became more associated with large groups of people working on a single major scientific question or technological problem – this was the advent of "big science" (Nye, 1996). However, as the NSES document points out, "pursuing science as a career or as a hobby can be both fascinating and intellectually rewarding" (NRC, 1996).

Alessandro Volta's "Voltaic Pile"

Alessandro Volta took delight in the fact that using simple materials such as various coins or metal disks, a salt solution, and porous paper or cardboard, he could produce a physiological sensation that we now recognize as an electric shock (Davis, 1995). Given these materials (specifically, pennies, nickels, dimes, quarters, zinc disks or squares, some lengths of copper wire, a saturated NaCl solution, some porous paper such as filter paper, and a low-impedance voltmeter), teams of students could conduct a simple inquiry activity to answer a question such as: Under what conditions can we use the given materials to produce an observable change in the voltmeter?

Upon completion of their investigation, the students should be able to indicate how they achieved the observable change in the voltmeter (i.e., how they got it to register), diagram the experimental setup and show alternative setups that did not work (false starts), show the conditions under which their own setup continues to work or ceases to work, and explain their results to the other teams.

The conventional route for carrying out this activity is to cut the filter paper into disks that are approximately the size of the coins. After the disks are saturated with the NaCl solution, they are layered alternately with coins containing two different metals (e.g., penny, dime, paper disk, penny, dime, paper disk). This voltaic pile has to be carefully constructed, and copper leads from the top and bottom of the pile are then attached to the leads of the voltmeter. The students may find that some combinations of coins do not work; quarters, nickels, and dimes are made of a similar cupronickel alloy. A CuZn cell produces about 1.1 V, so sufficient cells must be placed in series to cause the voltmeter to register.

Students may not immediately grasp the construction principle of the voltaic pile unless they have first been introduced to the concept of the complete circuit and the necessity of separating the different metals from one another by a medium that allows movement of ions. A preliminary activity using dry cells to light LEDs would be an appropriate introduction to the voltaic pile.

Follow-up activities could include the electrolysis of KI(aq) to produce I_2, to show the connection between electrochemistry and the discovery of the elements, an immediate application made by Humphry Davy following the discovery of the voltaic pile. Leads from a 9-V cell immersed in a KI(aq) solution in a petri dish is the simple experimental design.

An additional follow-up activity involves the simple electrolysis of water by inverting two small test tubes filled with a dilute Na_2SO_4 solution (or other appropriate electrolyte) over the leads of a 9-V cell and then immersing the whole assembly in a 250-mL beaker of the electrolyte solution. H_2(g) and O_2(g) quickly develop in the tubes in a volume ratio of 2:1, which can then lead to a discussion of the formula of water. Students will be amazed to know that many famous scientists, including Boyle, thought that the formula for water was HO. This misconception can lead to many questions: Why did Boyle accept the HO formula? How did we find out otherwise? What methods might we use to determine the formula of water? What difference does it make?

Water Wonderworks: *A Hydroinvestigator Casebook*
Water Wonderworks (1996) is an inquiry-based set of activities centering around all aspects of water. Aimed at the middle school student, the casebook presents several activities in which clues from the past are used to learn more about drinking water and the development of water testing using the pH scale. The emphasis is on water pollution and how to test for it; the students are given sets of problems to solve and then asked to present their results along with reasons for their conclusions.

Serendipitous Discoveries
Many discoveries in the chemical sciences were the results of accidents or errors. Any one of the "lucky accidents" described by Roberts (1989) in *Serendipity: Accidental Discoveries in Science* would make a fine basis for class discussion of the scientific method (or lack thereof), the nature of discovery, the role of human error in revealing new phenomena, and human persistence in seeking explanations of unexpected results. In addition to the well-known stories about Pasteur's discovery of chiral molecules, Perkin's discovery of synthetic dyes, and the accounts surrounding the discovery of many of the chemical elements, we can find many others related to the chemical sciences. The story of the discovery of the electric battery by Galvani and Volta would be an appropriate introduction to the construction of a voltaic pile.

The Human Side of Scientists (Oesper, 1975) is a collection of brief biographies of 132 men and one woman (guess who?). Oesper tells some delightful, sometimes apocryphal, stories about these scientists' idiosyncrasies and personalities. However, to set the record straight, *Women in Chemistry and Physics* is also a useful resource (Grinstein et al., 1993).

The Nature of Scientific Knowledge
The NSES are very clear on the importance of recognizing that scientific knowledge is based on "experimental and observational evidence about nature"; it is subject to confirmation, and explanations may change with new knowledge; and science knowledge is characterized by "empirical standards, logical arguments, and skepticism" (NRC, 1996).

Conant (1957), in his *Harvard Case Histories in Experimental Science*, argued that it was easier for the nonscientist *to* use the relevant historical record to examine the nature of science than to use a modern research project, given its complexity. By tracing the historical record, the informed layperson can see a whole new field of science unfold over time, recapturing the experiences of the scientists initially involved.

Students need some kind of structure to which they can attach the myriad items of chemistry knowledge they need to master. One good way to link together data is to show their historical connections (Benfey, 1996).

The Periodic Table Revisited

One of the most powerful organizational tools in chemistry is the periodic table. Many scientists tried over a period of several decades to make some sense out of the observed trends in properties of the elements as they were discovered. Today, we credit Mendeleev with the breakthrough concepts that led to the development of the modern periodic table. Mendeleev's table was empirical; it had no relationship to atomic structure and, indeed, not until 1904 was any suggestion made regarding a correlation between valence electron counts and the periodic table.

Presenting the periodic table outside the context of its historical development can give students the impression that all the concepts involved in developing the table fell into place at once. The students have little understanding of the struggle that Mendeleev and other scientists experienced in trying to bring order out of seeming chaos. The following exercise, from the periodicity module of *SourceBook* (Orna et al., 1994), gives some sense of the thrill of discovery and inquiry.
1

TABLE 12.1
Physical Properties of Elements on Xeno

ELEMENT	COLOR	HARDNESS	MELTING POINT (°C)
A	Turquoise	Soft	1050
B	Silvery to black	Hard	-300
C	Yellow	Sort	1000
D	Gray	Hard	400
E	Pink	Soft	1200
F	Silvery to black	Hard	-100
G	Silvery to black	Hard	-200
H	Black	Hard	300
I	Aqua	Soft	900
J	Brown	Soft	1000

The Elements on the Planet Xeno
Imagine that you have landed on another world, where the average temperature is –320 °C. As you explore, you discover that the elements here seem to differ from those on Earth. You manage to collect 10 of these elements and determine their physical properties, which are listed in Table 12.1.

Stage 1: Group these elements into a tentative periodic table on the basis of their physical properties. Justify your groupings.

TABLE 12.2
Chemical Properties of Elements on Xeno

ELEMENT	REACTS WITH WATER	REACTS WITH ACID	REACTS WITH OXYGEN	NO REACTION
A			X	
B	X	X	X	
C				X
D		X	X	
E				X
F	X	X	X	
G	X	X	X	
H	X	X	X	
I			X	
J		X	X	

Stage 2: You now decide to collect data on the chemical properties of these elements. Using the data listed in Table 12.2, modify your original periodic table. Justify your new arrangement.

Stage 3: You now find that to continue further, you must determine the relative atomic masses of the elements. After obtaining the data from Table 12.3, modify your periodic table and justify your new arrangements.

TABLE 12.3
Relative Atomic Masses of Elements on Xeno

Element	A	B	C	D	E	F	G	H	I	J
Relative Atomic Mass	5	3	1	7	10	15	9	14	1	6

Teaching notes. Stage 1-The first arrangement might look like Table 12.4. Notice that the melting point increases across a period and down a group, whereas hardness decreases. (At this stage, it is equally valid to arrange the elements so that melting point decreases across a period or down a group.) The elements on the left are all silver to black; those in the middle, dark-colored; those on the right are brightly colored. (With the information given, element J could also be put in the right group, either above or below C.)

TABLE 12.4
Stage 1 Arrangement

B	-333	H	300	I	900
G	-200	D	400	C	1000
F	-100	J	1000	A	1050
				E	1200

Stage 2– Table 12.5 reflects similarities in chemical properties. Since B, G, and F show the same chemical properties, the left group remains intact. The middle group is split in two with H on the left because its chemical properties are identical to those of the elements in the left group. D and J do not react with water, so they are closer to the elements in the right group.

TABLE 12.5
Stage 2 Arrangement

B	H	D	I	A
G		J	C	E
F				

Stage 3 – After the atomic mass data are taken into account, the final arrangement of the elements on the planet Xeno might look like Table 12.6. Notice that the brightly colored elements are now on the left side of the table. Xeno's unreactive elements (C and E) are on the left side of the table, whereas Earth's noble gases are on the right. Xeno's hard, silvery elements would be gases at 25 °C (Earth's room temperature) and are on the right, whereas Earth's metals are solid at 25 °C and are on the left side of the table.

This table now has three periods and six families (groups). It has places for 18 elements, 10 of which are known. The properties of a missing element should follow the trends in properties within its period and group.

TABLE 12.6
Stage 3 Final Arrangement

C	I				B
	A	J	D		G
E				H	F

Although it is easy to record the physical properties given in Stage 1, these properties by themselves do not give enough information to build a periodic table. The chemical properties from Stage 2 are very useful, but the best information is the relative atomic masses from Stage 3.

Students can be asked to record the similarities between the process of building a table for elements on Xeno and the historical development of the periodic table on Earth.

Historical Perspectives
How did modern chemistry develop? Not long ago, few students had much interest in the answers to this question—they were more focused on the present and the future.

Times have changed, partly because today chemical scientists are often on the defensive. Chemistry has had bad press. Pollution, industrial accidents, the negative side effects of medications—all make headlines, and all add to the negative image of the chemical sciences. Improvements in the quality of life—increased longevity, advances in food safety, healthcare, and so forth—are taken for granted and not credited to the work of chemical scientists. An awareness of the pivotal role of chemical scientists in contributing to our present way of life can do much to overcome the negative images generated by bad press. To see chemical activity as a communal exploration of the unknown—exemplified by courage, creativity, and powerful intelligence—restores pride and adds perspective.

We must make it clear that diverse cultures have contributed to scientific knowledge through the centuries. Ihde (1984) has suggested that three parallel streams—medicine, alchemy, and metallurgy (or technology)—played a significant role in the development of chemistry through the so-called protochemical, or pre-Boyle, era. (It is with Boyle, and the rise of the phlogiston theory in the mid-seventeenth century, that we mark the beginnings of chemistry as an abstract science.) Many non-European cultures have contributed to the development of scientific ideas and technology, as documented by Hayes and Perez (1997).

Overthrow of the Phlogiston Theory
One of the keystones of the phlogiston theory was the idea that, upon combustion, a substance called phlogiston was lost by the material undergoing combustion, so that the total mass of products following combustion was less than that of the material before burning. For example, when paper burns, the mass of the resulting ash is clearly less than the mass of the original paper. However, some combustion processes actually result in a mass increase.

Robert Boyle, a convinced phlogistonist, noticed this phenomenon even when combustion took place in a sealed chamber, and he chose to ignore the inrush of air following combustion when the sealed system was opened up. Some phlogistonists even postulated the concept of negative mass in order to make the phlogiston theory fit the facts. Thus, the gain in mass did not convince the most dedicated phlogistonists. However, it provided support for Lavoisier's theory that oxygen combined with burning material to form new substances with a combined total mass greater than the original because of the added oxygen.

A common laboratory activity that can be placed in this historic perspective is the combustion of magnesium to form magnesium oxide. Typically, students weigh a crucible containing magnesium before and after heating. The increase in mass is explained by the combination of oxygen in the air with the magnesium. From the data obtained, it is possible to determine the formula of the oxide of magnesium if the relative atomic masses of magnesium and oxygen are known. Students can be asked to reconcile their results with the Lavoisier theory and with the phlogiston theory. They can also be asked why burning a piece of paper does not provide immediately obvious support for Lavoisier's theory, what additional information is needed to reconcile every combustion process with Lavoisier's theory, and what additional hypotheses must be put forward to reconcile every combustion process with the phlogiston theory. Thus, they may gain some appreciation for how difficult it was to overthrow the phlogiston theory.

Conclusions

As Schwartz observed in his paper illustrating the uses of history to teach chemistry (1996), the historical approach provides

- context for the content of the chemical sciences,
- .demonstrations of scientific methodology,
- examples of resolved and unresolved ambiguity,
- evidence of the humanity and diversity of chemical scientists,
- illustrations of imagination and creativity, and
- insights into human values and the nature of truth.

In this chapter I have attempted to provide some of these insights as a framework on which to hang some very interesting tales. However, it is very important that teachers develop their own stories. Some additional sources include Conant's *Case Histories in the Chemical Sciences* (1957); Burke's *Connections,* a brilliant examination of the ideas, inventions, and coincidences that have culminated in the major technological achievements of today (1978); and *Chemical Curiosities,* a handbook of spectacular demonstrations and inspired quotes, many with their roots in the fundamental discoveries that form the basis of modem chemistry (Roesky and Mockel, 1996). A general philosophical reference may be helpful for context setting; one such reference is *Science and Its Ways of Knowing* (Hatton and Plouffe, 1997).

I hope that these references, along with ideas gleaned from other sections of this book and elsewhere (such as Layman's *Inquiry and Learning,* 1996), will provide a good starting point for realizing this particular science standard in the classroom and the laboratory.

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CHAPTER THIRTEEN

Preservice Science Teacher Education and the National Science Education Standards

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Becoming an effective science teacher is a continuous process that stretches from preservice experiences in undergraduate years to the end of a professional career (NRC, 1996).

As we look toward the next millennium, teacher education programs, especially those for preparing high school chemistry teachers, will attempt to address the issues raised and achieve the goals set by the National Science Education Standards (NSES). For the past decade, reform documents have called for preservice programs to prepare teachers who will

- learn their chemistry through inquiry,
- understand the connection of chemistry to everyday events and other sciences, and
- demonstrate proficient knowledge of content and pedagogy and of pedagogical content knowledge.

These goals should be achieved while preservice teachers are completing the required course work for a chemistry degree; the reform documents specifically note how important it is that high school teachers have degrees in their content areas (NRC, 1996, 1990).

At the same time, the National Council of Accreditation of Teacher Education and other national bodies that accredit universities' teacher education programs have required increased course work in education and "practical" experience in teaching. At the K-12 level, the call is for "less is more" in terms of content. But this is not the case for preparing chemistry teachers. Our new teachers are expected to know chemistry and take enough other science courses to teach an interdisciplinary science course. We also expect teachers to know chemistry in enough depth to become involved in "wet-bench" chemistry research, either as undergraduates or as part of their continued professional development. In an ideal program, preservice teachers would complete at least one educational research project in addition to these requirements. How can we prepare future teachers to meet these standards? Inservice teachers who supervise the field and student teaching practica of student teachers are key to this process.

Having an impact on the teaching style of a novice teacher is a challenge. Regardless of whether students have progressed through a detailed educational program or are completing the required courses for teaching certification, they have developed strong ideas about teachers and teaching through years of observation in different educational settings (school and university). Often, the types of teaching experienced by college-level students are the antithesis of the pedagogy proposed in the NSES.

Most preservice teacher education programs and state certification agencies require students to complete field experiences and/or a student teaching practicum. These experiences are supervised by university personnel and by inservice teachers. It is in this supervisory, mentoring role that college-level chemistry teachers can assist teacher education programs to produce teachers whose pedagogical practices meet the NSES. Table 13.1 shows the changing emphasis for teaching proposed in the NSES.

TABLE 13.1

Changing Emphasis in Teaching Standards

LESS EMPHASIS ON	MORE EMPHASIS ON
Transmission of teaching knowledge and skills by lectures	Inquiry into teaching and learning
Learning science by lecture and reading	Learning science through investigation and inquiry
Separation of science and teaching knowledge	Integration of science and teaching knowledge
Separation of theory and practice	Integration of theory and practice in school settings
Individual learning	Collegial and collaborative learning
Fragmented, one-shot sessions	Long-term coherent plans
Courses and workshops alone	A variety of professional development activities
Reliance on external experiences	Mix of internal and external expertise
Staff developers as educators	Staff developers as facilitators, consultants and planners
Teacher as technician	Teacher as intellectual reflective practitioner
Teacher as consumer of knowledge about teaching	Teacher as producer of knowledge about teaching
Teacher as follower	Teacher as leader
Teacher as an individual based in the classroom	Teacher as a member of collegial professional community
Teacher as target of change	Teacher as source and facilitator of change

Although university science departments are slowly beginning to change their chemistry curricula to teach using inquiry, problem-based and cooperative learning, and other teaching approaches, the majority of teachers graduate from programs that use lecture and "cookbook" labs as the primary pedagogies. While the standards call for a variety of teaching strategies with an emphasis on inquiry, small-group work, and non-cookbook laboratories, the reality is that many preservice teachers will have never experienced these teaching approaches. How can we assist preservice and beginning teachers to attain these standards? Teachers who are supervising a practicum need to model the exemplary teaching practices noted in the NSES for student teachers.

Characteristics of New Teachers

Because mentor teachers interact daily with student teachers, they are prominent influences in the development of the next generation of practitioners. When student teachers begin their practical experience, they often rely on the pedagogical practice they have experienced the most: lecturing.

If beginning teachers spend time developing good lesson plans that reflect a variety of teaching strategies, they are less likely to use lecturing as the only or dominant teaching strategy. Supervising teachers can insist that their student teachers write detailed lesson plans that reflect an emphasis on inquiry rather than the transmission of knowledge.

For classroom observation to be of value, the supervising teacher and the student teacher together should first determine objectives for the lesson. Observations may last from a few minutes to a full class period, depending on the purpose. Most result in anecdotal information. If you are serving as the exemplary teacher, be sure to write down your notes and thoughts, discuss them with your student teachers, and give them a copy to reflect on later. For each observation, note the time (in minutes) that the student teacher took to begin the lesson, spent on each type of teaching activity, and took to end the lesson.

The teaching activities could be lecturing, providing notes, a question-and-answer session, whole-class or small-group work activities, individual work, or laboratory. By being specific and documenting the time allocated to each teaching activity, you provide the student teacher with data that may be used to improve classroom practice (see Table 13.2).

Lecturing and cookbook labs have a place in the curriculum, but they are not the only methods by which student teachers begin to learn their craft. We need to encourage student teachers to try new teaching and assessment techniques such as group work, cooperative learning, and alternative approaches to assessment.

Student teachers often use target students to keep their lessons progressing. Target students usually dominate the lesson and prevent other students from participating and contributing. Teachers can use small groups and cooperative learning to minimize this; however, if the teacher does not carefully monitor smaller groups, there often emerges a target student within each group (Tobin and Gallagher, 1987).

TABLE 13.2

Teaching Emphasis in Beginning Teachers

LESS OF THIS	MORE EMPHASIS ON
Lecturing as the primary teaching mode	Teaching through inquiry
Using cookbook labs	Labs requiring students to solve problems
Algorithmic worksheets	Using chemistry to solve real-world problems
Relying on target students	Involving all students in the lesson
Asking primarily knowledge-level questions	Asking primarily higher cognitive-level questions
Test/exams with only multiple-choice questions	Test/exams with a variety of questions: multiple-choice, short-answer, problems

Teacher mentors can help student teachers minimize their use of target students by noting the student teacher's interactions with the students. This can be done by taking a class seating chart and noting the number and type of interactions between the student teacher and the students. On the seating chart, identify the students by name, initials, or a number. You may also want to indicate other relevant information such as race, sex, or ability level. Code all students' interactions with the student teacher by placing a hash mark in the appropriate box. After the observation, share the chart with your student teacher. The hash marks give a quick and easy visual picture of the pattern of interactions. In addition to looking for a balanced physical pattern (e.g., calls on students throughout the room, not just those in front), you can also look for balanced gender and ethnic patterns.

The coding may be further refined by noting the level of question that a student is asked. Student teachers often ask knowledge-level questions, in rapid-fire succession, as a strategy to control students and maintain order in the class. Whereas this may help with classroom management issues, it does not give students time to consider the concepts being taught. Often, less than 10% of the questions student teachers ask will be above the knowledge level. You can use letters to identify the question types as follows: knowledge (K) questions, which are fact-based, involving recall; and upper-level (U) questions, which are more conceptual in nature, such as those involving synthesis, problem-solving, or critical-thinking skills.

Mentor teachers can encourage student teachers to consider how they may teach the same concept to different levels of students, and/or students with different learning abilities. Encourage your student teachers to provide different lesson plans for the same topic, but with different student groups.

Professionalism

The teaching standards encourage teachers to remain aware of recent developments in their discipline that enhance their science knowledge.

Beginning teachers can do this by taking advanced courses and reading popular magazines such as *Time, Newsweek,* the science section of the *New York Times, The Journal of Chemical Education, ChemMatters,* and *Chemical & Engineering News.*

As a mentor teacher, you can encourage your student teachers to join their professional associations and, when possible, attend the national and regional meetings of organizations such as the National Science Teachers Association and the American Chemical Society (ACS)—especially the biennial conferences on chemistry education and programs run by the ACS Division of Chemical Education. In addition, remind your student teachers that the costs are lower for students. The journals published by these organizations provide educators with ideas for improving teaching and opportunities to interact with their colleagues.

There are many such professional opportunities for teachers within local, state, regional, and national organizations. Encourage beginning teachers to use all possible resources, such as journals, the World Wide Web, and district information.

Long-Term Planning
Long-term lesson planning is a skill to be developed. Mentor teachers can insist that their student teachers write complete topic and unit plans, not just daily plans. A topic plan would consist of three to six lessons, whereas a unit plan would be an overview of several (at least three to six) weeks of teaching. Although there are many published topic and unit plans, they usually have to be tailored to the needs of each specific class. The professional teacher is constantly seeking new ideas for lessons that will meet a particular class need.

Reflective Practice
The standards challenge us to rethink and reassess our own teaching experiences, both as students and as professionals. Teachers constantly reevaluate lessons, programs, tests, teaching ideas, and labs. New teachers should be encouraged to reflect formally on their instructional practices by videotaping and critiquing them at least twice during the student teaching experience. Ask your student teacher to take notes or videotape your teaching and/or questioning strategies. Also, student teachers should be encouraged to rewrite lesson, topic, and unit plans after they have taught the lessons. They need to keep in mind questions such as, "What worked and why? What didn't and why? Were all students engaged in the lesson?"

Using multiple forms of assessment is another important skill for future teachers. Ask your student teachers to analyze the results of tests that they give to your students and, on the basis of those results, revise the test for the next group of students.

Most teachers engage in forms of research in their classes. Regardless of the research questions, teachers produce professional knowledge from their teaching experiences. They constantly collect observational data and reflect on whether a situation needs to change; then they plan actions to make that change and evaluate the results of their actions. All of these activities are constantly informed by reflection. Teachers who are reflective practitioners are producers of knowledge on teaching.

Professional Community
Traditionally, teaching has been an isolated profession. With electronic networks, a teacher's professional community can be expanded from the classroom or school to the world. Beginning teachers can use electronic networks to find and keep in contact with mentors and role models and solicit moral support as they begin the path to becoming professionals.

NSES have set high standards for the teaching and learning of science. Although teacher education programs have begun the reforms needed to promote teachers who can meet these standards, we are still in a transition stage. We need the help of experienced chemistry teachers in the field who can shape beginning teachers' instructional methods during student teaching practice so that they reflect the challenges presented by the national standards.

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CHAPTER FOURTEEN

Standardizing Assessments for Assessing Standards

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The impact of the National Science Education Standards (NSES) on American science education is likely to be the most far-reaching of any post-Sputnik educational event. Educators are scrambling to realign curricula to address the learning goals of the NSES, yet the fundamental problem of knowing whether students are achieving these goals remains. The traditional measures, including standardized examinations designed to assess modest acquisition of cognitive knowledge, are inadequate (and inappropriate) to assess student gains in understanding such topics as how scientists develop their understanding of the natural world. In fact, if we consider the changes in curricular emphasis recommended by the National Research Council (NRC) (under the auspices of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine, and with the financial support of the National Science Foundation, the U.S. Office of Education, the National Institutes of Health, and the National Academy of Sciences--wow!), we discover a basic shift away from students knowing what science has discovered and toward how science knowledge is gained.

If we as teachers embrace the content of the NSES, then we must redesign assessment instruments even as we are reworking curricular content, emphases, and instructional paradigms. The history of educational reform is replete with examples of new instructional strategies that showed no apparent gains in student achievement or response—not because the gains were not there, but because the measuring instruments were insensitive to the gains. In fact, the assessment criteria for the standards should be put in place before any instructional change is contemplated. With well-thought-out assessment materials in place, we can objectively evaluate alternative instructional strategies targeting the goals outlined in the NSES. The alternative is to find ourselves in the oh-so-familiar situation of designing new instruction and then trying to figure out how to tell if anything has been accomplished.

Getting Down To Specifics

The summary assessment challenges suggested by the authors of the standards are laid out in Table 14.1 (NRC, 1996). The NSES call for changes throughout the system. The assessment standards encompass these changes in emphasis.

Table 14.1
Increasing Emphasis

Less of This	More of This
Assessing what is easily measured	Assessing what is most highly valued
Assessing discrete knowledge	Assessing rich, well structured knowledge
Assessing scientific knowledge	Assessing scientific understanding and reasoning
Assessing to learn what students do not know	Assessing to learn what students do understand
Assessing only achievement	Assessing achievement and opportunity to learn
End of term assessments by teachers	Students engaged in ongoing assessment of their work and that of others
Development of external assessments by measurement experts alone	Teachers involved in the development of external assessments.

The entries in Table 14.1 are not easy to understand out of context, and the theme of this piece is to interpret and amplify these recommendations and then to provide concrete examples of how achievement in the specified areas could be measured. Keep in mind that the standards address changes in emphasis, not complete replacement of existing assessment practices.

Easily Measured vs. Highly Valued

The assessment standard for highly valued learning (see Table 14.2) is, in a sense, an umbrella for several of those that follow. The basic idea embodied here is that we consider desired student outcomes, such as being able to use the knowledge they have acquired to deal with new, unfamiliar circumstances or to recognize situations in which additional information is needed before rational conclusions or inferences can be drawn. Almost universally, we want our students to process information, not just regurgitate it. Is it, for example, sufficient to be able to recite the properties of common acids and perform cookbook, algorithmic laboratory manipulations? Or should students be able to use their knowledge of acids and bases to develop their own methods of dealing with less structured problems?

The really difficult task for the teacher or assessment professional is to express what is "highly valued" in terms that lend themselves to measurement. We commonly hear teachers lament, "If only my students would learn to think." We'll never know whether they can think or not unless we provide an opportunity for them to demonstrate that they can.

Table 14.2
Increasing Emphasis on What is Highly Valued

Less of This	More of This
The student is given a standardized 0.100 M NaOH solution, and HCl solution of unknown concentration, phenolphthalein, and a titration setup. The student is instructed to determine the concentration of the HCl solution.	The student is given four solutions labeled A, B, C, or D and a titration setup. The solutions are chosen from this list. Each acid solution also contains phenolphthalein. **Possible Acid Solutions** — **Possible Basic Solutions** 1.00 M HCl — 1.0 M NaOH 0.50 M HCl — 0.5 M NaOH 0.10 M HCl — 0.1 M NaOH The student is to use the most concentrated acid solution in the group of four to determine the concentration of the most dilute basic solution. The student must describe both the method developed to solve the problem and the results.
Comments: This is a straightforward laboratory exercise that most students deal with by following explicit directions or by rote. There is one "right" answer.	**Comments:** This exercise requires students to plan and carry out their experiment, make and interpret observations, and communicate their thought processes. A well-designed scoring rubric includes partial credit for the various subtasks. This style of activity reduces the student's dependence on algorithms. All students will have some success with this activity, but there are several paths to a successful out come. Content knowledge and process skills are both required. The lack of knowledge of just one fact, such as the color of phenolphthalein in acid or base, does not totally jeopardize the demonstration of knowledge and skills. Depending on the assessment goals, such activities can be carried out individually or cooperatively. (a)

Discrete Knowledge vs. Rich, Well-Structured Knowledge

At every level of science instruction, teachers acknowledge that there are some concepts, ideas, and skills that lend themselves to quick, unambiguous assessment. When we ask a student to calculate the molar mass of a compound, balance a chemical equation, give the shape of a molecule, or write formulas for the products of a redox reaction, the answer is unambiguous and student success with the task can be measured with certainty. But are such algorithmic skills really central to what our course is attempting to teach? Or are we trying to bring students to the point of understanding the nature of processes well enough to conceptualize what is happening at the molecular level rather than simply following learned algorithms? Can students, for example, understand in a more general sense the nature of oxidation and reduction well enough to recognize why some metal objects they use corrode away while others remain shiny and bright? Can they understand why the manufacture of hydrogen for fuel requires more energy to produce it than is subsequently released in its combustion? Table 14.3 illustrates this shift in emphasis.

Table 14.3
Increasing Emphasis on Well- Structured Knowledge

Less of This	More of This
Given the formulas for molecular oxygen, molecular hydrogen, and water, along with a table of bond energies, the student is asked to write a chemical equation to represent the electrolysis of water and calculate the enthalpy change for the reaction.	Given this structural diagram representing water molecules and a table of bond energies, students draw a diagram to represent the molecular view of the products of electrolysis and to describe the outcome of electrolysis in terms of the predicted physical states of the products and the energy released or consumed in the process.
Comments: Most introductory chemistry students can write the equation for water being electrolyzed into hydrogen and oxygen gases. This symbolic representation is often just that, however, with no fundamental conceptual understanding of the nature of the products or the energy relationships involved in making and breaking chemical bonds. Students tend to be much less successful with the energy calculation because of their lack of conceptual understanding of the bonding involved.	**Comments:** This question requires students to think about the bonding of atoms in molecules, an to demonstrate understanding by first preparing their won sketch of the products, and then considering bonds broken and bonds formed, molecular masses, and shapes and polarities of the product molecules. Students are expected to conclude from these considerations that gaseous products result, with a substantial input of energy.

The point of this assessment standard is that we cannot expect broad, general understanding if we only assess "bite-sized" chunks of information. There is little doubt that the ability to understand the broad principles of science, and to transfer and apply that knowledge to new situations, is the hallmark of a scientifically literate person. The debate among science educators for generations has centered around whether a person can successfully interpret new science-based events and information without being well grounded in transferable knowledge. The authors of the standards clearly wish to see assessment greatly broadened and enriched, and teachers are just beginning to figure out how to do this very difficult job.

Table 14.4 Increasing Emphasis on Reasoning Like a Scientist	
Less of This	More of This
The student is asked to explain why chlorine is used for the treatment of most municipal drinking water.	The student is told that chlorination of water offers advantages and disadvantages and is to evaluate statements to judge whether the advantages outweigh the disadvantages: • Chlorination kills most water-borne bacteria. • Heavy metal ions are removed by chlorination. • Trihalomethanes (THMs) may be produced if chlorine is added to water containing organic matter. • Of the various methods for sanitizing water, chlorination is least expensive. • There is a reduction in tooth decay as a result of chlorination. • Ozone and ultraviolet light can also be used to sanitize water and are safer than chlorination.
Comments: This is a simple question that is based on recall	**Comments:** Most students can enjoy some success with this approach, even if there are significant gaps in their understanding of one or more of the subtopics.

Scientific Knowledge vs. Scientific Understanding and Reasoning
How does one think like a scientist? Is there really a "scientific" way of thinking about things that distinguishes itself from the way mere mortals think about things? We doubt it. Our experience is that scientists and nonscientists use their intellectual tools in pretty much the same way. The difference is that scientists have a larger toolbox when addressing problems that are amenable to scientific scrutiny. As Isaac Newton very humbly wrote, "If I see farther, it is because I stand on the shoulders of giants." Regardless of the knowledge tools that anyone brings to bear on a problem, the evaluation and reasoning process can be pretty much the same (Table 14.4).

What Do Students Not Know vs. What Do They Understand
All teachers can cite painful examples from their own days of formal education when they asked the one thing that the student did *not* know (or at least what the student perceived to be the one thing he or she did not know)! This is an extension of that well-known phenomenon in which the teacher calls on students only on the days they are unprepared. Furthermore, the questions may not be posed in a manner that enables the students to reveal their full knowledge of the subject. What we would really like to be able to say to the student is, "Tell me everything you know about topic X, and tell it to me in such a way that I can easily fit it into a scoring rubric." One practical approach is to structure questions so that students can answer in several ways and receive credit for partial understanding, as Table 14.5 illustrates.

Table 14.5 Increasing Emphasis on finding Out What Students Do Understand	
Less of This	More of This
The student is given the formula of a particular covalent compound and instructed to use VSEPR and electronegativities to determine the molecular shape and polarity of the compound.	The student is reminded that polar covalent compounds have the center of positive charge located away from the center of negative charge in the molecule. The student is to describe the factors that come into play in determining whether compounds are polar or nonpolar. The student is free to use any or all of these tools: electronic structures, Lewis dot-structures, VSEPR, orbital hybridization, electronegativity, ionization energy, electron affinity, and atom sizes.
Comments: Students can succeed with this multi-step problem only if they recall the general characteristics of covalent bonds, details of bond polarities based on electronegativity differences and molecular symmetry based on VSEPR. The chances of incorrect response are very great.	**Comments:** Most students can enjoy some success with this approach, even if there are significant gaps in their understanding of one or more of the subtopics.

Achievement Alone vs. Achievement and Opportunity To Learn
Appraisal of the learning environment as a significant factor in determining what a student can achieve is acknowledged by most educators as a special concern. However, it is anything but easy for either classroom teachers or assessment professionals to figure out how to deal with the issue. It is somewhat easier, on the other hand, to recognize that the students coming into our classes are not homogeneous. Some are farther behind (or farther ahead) than their innate intelligence would suggest because of poor (or excellent) learning environments they have experienced in the past. Rather than attempting to index the "opportunity to learn" to factors originating outside the classroom, we believe it is more realistic to consider *incremental gains* that students make under an individual teacher's tutelage, and that is the way we have chosen to deal with this assessment standard.

Incremental gain is traditionally determined through some variant of a pre-test/post-test strategy. The major concern is that these instruments be genuinely congruent with the objectives of the instruction that is sandwiched between. The assessments, for example, should be sensitive to the criteria that have already been discussed. In addition, race and gender bias of the instruments themselves must be carefully considered in establishing the benchmarks for measuring incremental gain, as must physical handicaps and lack of language proficiency.

Teacher-Driven End-of-Term Assessments vs. Ongoing Student Assessment
Classroom chemistry teachers are also, in a sense, researchers in chemical education, whether or not they see themselves that way. Feedback from classroom assessment is used either formally or informally as teachers plan their instruction and adjust pace and depth on the basis of how students are learning. In these days of increasing accountability, it is not surprising that many teachers are somewhat reluctant to release any of their responsibility for assessment to the students, but student learning is enhanced when students take greater responsibility for their own learning. By implication, the NSES suggest that students can take more responsibility for their own assessment as well (Table 14.6). In fact, efforts to reduce the emphasis on external or teacher-generated end-of-term assessments and to increase the emphasis on ongoing student assessment have met with substantial success. When students feel that their input is valued, they are more successful. One such recent experiment in allowing students a greater role in ongoing assessment led the teacher researcher to remark, "As an educator, this process has renewed my belief that students want to be involved, are ambitious, and want to be challenged" (Lundbert, 1997).

Measurement Experts Vs. Teachers' Roles In External Assessment
If it is true that most teachers start by teaching in the way they were taught, then it is certainly true that most teachers carry out assessment in the way they were assessed. We are all painfully aware of the many demands on our time, and developing better student assessments is often not the item with highest priority on our list. As if writing classroom tests and developing other assessment activities were not enough, does it seem reasonable that the NSES expect teachers to shoulder an increasing share of the work in designing student assessments?

Table 14.6
Increasing Emphasis on Student Participation in Assessment

Less of This	More of This
Students are given data for dissolved oxygen concentration on the y-axis, as a function of temperature on the x-axis, and to identify the temperature at which fish have the most available oxygen.	Groups of students are given temperature and dissolved oxygen data for each month of the year from a stream. Each group is to develop a graphical display involving any relevant variables (month, temperature, dissolved oxygen concentration) that will help nonscientists understand the variation in dissolved criteria to evaluate the clarity with which various graphical displays communicate this information to the public. (See also Chapter 11.)
Comments: This is a typical graphing exercise that students tend to do by rote.	**Comments:** Students develop many responses to activities such as this and tend to be very perceptive in evaluating the effectiveness of various graphical displays in communicating information

Two factors stand out. The first is that only through the active involvement of the teachers will content validity and construct validity be maintained. Practicing teachers are the ones who know how students respond to changing curricular content and instructional paradigms, and they are the ones that can effectively make contributions to regional, state, and national assessment reform. The second factor strikes at the heart of what it means to be a professional. Teachers who actively participate in designing curricula and assessment activities routinely report that they experience intense professional growth. As long as administrators and school districts understand that teachers need to be supported and encouraged to participate in such important professional activities, teachers willingly, even eagerly, participate in this creative component of the teaching-learning process.

Having more teachers with a professional stake in large-scale external assessment can have the beneficial effect of discouraging the misuse of the data generated by such assessments. Tests designed for student assessment, for example, should not be confused with those designed for program assessment. For more than 70 years, teachers have been, and continue to be, the measurement experts in constructing chemistry assessment examinations for the American Chemical Society (ACS) Division of Chemical Education (DivCHED) Examinations Institute (see references below).

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CHAPTER FIFTEEN

The Impact of the Standards on Advanced Placement Chemistry

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Advanced Placement (AP) chemistry, theoretically the equivalent of first-year college or university chemistry, is taught to superior students while they are still in secondary school. It is viewed by the College Board as "an opportunity for secondary school students to pursue and receive credit for college-level course work at the secondary level" (CEEB, 1988).

The AP program was started in the 1950s to meet the educational needs of those abler secondary school students who are capable of handling college-level studies but are not necessarily mature enough to handle the social and other aspects of tertiary education. More details can be found in the above-cited manual.

Thus, at first glance, it would appear that the National Science Education Standards (NSES) should have no impact on AP chemistry. The standards describe the minimal K-12 science background "for all Americans" (NRC, 1996). The *Advanced Placement Course Description for Chemistry* (called the "acorn chemistry booklet" from the College Board acorn logo on the cover) provides broad recommendations for the topics and skills to be covered in an AP chemistry course (CEEB, 1996a). The acorn booklet content is based on topics covered in the first-year college chemistry courses of most colleges and universities, as deduced from surveys of college and university chemistry departments and the expertise of the College Board Chemistry Development Committee.

The Need for Change

College and universities will need to adapt their introductory chemistry courses as the science education of high school students changes because of the NSES. In turn, these changes will modify the content (and pedagogy) of AP chemistry. The College Board Chemistry Development Committee meets at least twice each year, so any extensive changes in the teaching of college chemistry should be immediately evident. However, some lag time may occur in the printing of each new acorn booklet for the subsequent academic year.

Changing Science Experiences

The nature and content of the science experiences of secondary school students will be different in standards-oriented programs from the current traditional secondary school courses. More inquiry-based and less specific fact knowledge is anticipated as the NSES are implemented. College and university faculty members will need to modify their courses to take advantage of the new learning skills the students will bring to the classroom. However, some of the science content knowledge expected of students in the past may not be part of their experiences under curricula designed to address the new learning goals. Thus, college chemistry courses may have to "fill in the gaps" that the college teachers identify to meet the content requirements of first-year chemistry courses for science majors.

Other Forces for Change

At present, the National Science Foundation is supporting five different consortia of colleges and universities in an effort to reform undergraduate chemistry, especially in the first two years. Also, the American Chemical Society (ACS) is developing a new first-year chemistry course that places chemistry within a biological context. All of these initiatives could have an impact on AP chemistry—perhaps leading to the development of two or more AP chemistry examinations should the new college programs prove popular.

Physics already has three different AP course examinations: B, which is based on a full-year general physics course; C—Mechanics, which is based on a one-semester course; and C—Electricity and Magnetism, also based on a one-semester course. Several other subjects offer at least two different AP course examinations. However, no attempt has been made to provide an AP analogue to the first-year organic chemistry courses being taught at a few universities (e.g., Brown University had a first-year organic course even when AP chemistry was first offered, and the University of Michigan has offered one for several years). Until a sizable number of colleges and universities adopt one of the new programs, it appears unlikely that any new formats for AP chemistry will be developed.

Changing Emphases In AP Chemistry

Over the past decade, three changes in emphasis have occurred in the AP examination involving: the laboratory portion, the reinclusion of organic molecules in the examination, and the use of equations rather than their memorization. A few topics have been removed, but surveys indicate that the vast majority of colleges and universities report that they teach almost all of the topics in the acorn chemistry booklet.

Laboratory
A greater emphasis is being placed on laboratory experiences. The CEEB surveyed students taking the AP chemistry examination and found that many high school teachers had decided that their students needed more time in lecture topics or that it was impossible to provide longer laboratory periods in their high schools. The committee found that better test scores were obtained by students with significant laboratory experience. To add pressure for the inclusion of substantial laboratory experiences in AP chemistry courses, laboratory questions have been placed on both the essay and the multiple-choice sections of the AP chemistry examinations. Also, the recommendation has been made by the ACS that colleges request the laboratory notebooks of AP students before awarding the students college chemistry laboratory credit. The current acorn chemistry booklet notes that

Because chemistry professors at some institutions ask to see a record of the laboratory work done by an AP student before making a decision about granting credit, placement, or both, in the chemistry program, students should keep reports of their laboratory work in such a fashion that the reports can be readily reviewed.

The latest acorn chemistry booklet also includes a detailed (20-plus pages) discussion of the AP chemistry laboratory program, what should be gained from the program, and the continuum of inquiry so important in scientific investigations— observing facts, proposing explanations to be tested, designing and carrying out experiments, expressing conclusions, and so forth. The emphasis is on providing students with many traditional laboratory exercises and giving them the opportunity to conduct novel investigations that help them learn how to engage in this continuum of inquiry.

Organic Molecules
A greater emphasis is being placed on including organic molecules in the AP chemistry examination. A knowledge of basic organic functional groups, nomenclature, and chemical properties is expected. Whereas detailed organic reactions per se are not included, organic molecules are used to illustrate concepts such as bonding, equilibria involving weak acids, kinetics, colligative properties, and stoichiometry.

Equations
Numerous equations that are potentially useful for solving AP-type problems are provided in the 1996 AP chemistry examination (CEEB, 1996b). Previously, only a hint of the Nernst equation was provided, but the 1996 examination gives five atomic-structure equations; nine equilibrium equations; nine thermochemistry equations; twelve equations related to gases, liquids, and solutions; and four equations related to oxidation-reduction and electrochemistry. Thus, AP students can concentrate on principles rather than memorizing mathematical equations.

On the other hand, the necessity of knowing some chemical facts has been reemphasized in the 1996 examination by placing the chemical reactions question—a long-time feature of AP chemistry examinations—up front as the first question on the free-response portion of the examination. A 10-minute time segment is provided just for showing a basic knowledge of reactants and products for five of eight common chemical reactions. Other basic facts are also necessary for the multiple-choice portion of the examination.

The Wrong Impact?
Because of budgetary concerns, some secondary school governing boards may assume that they can teach NSES-based science to all of their students without increasing the number of science teachers in their schools. This is completely unrealistic. Currently, only a fraction of high school students take science for four years. Therefore, schools without added teachers will face the prospect of teaching science to all students with insufficient staff. Which courses will be left out of the curriculum as a school struggles to teach NSES-based science to all students? The current high school science courses for science-oriented students modified to address the NSES? Advanced courses such as AP chemistry?

While the national standards related to chemistry provide a sound general knowledge base for all students, they do not include sufficient mathematical content to prepare prospective college science students, unless additional content is added. Thus, it will be important that appropriate science education experiences beyond the learning goals defined by the NSES be made available to these students. The present AP chemistry course is designed to be taken only after the successful completion of a first course in high school chemistry and should not take the place of a year of high school physics. However, a good science background through the NSES could change this perspective. Only time will tell.

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CHAPTER SIXTEEN

Reform and Resources

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(This chapter is adapted from a speech given at a symposium held at the American Chemical Society New Orleans national meeting in March 1996, to honor the memory of Dr. Allan McClelland of the DuPont Company and the National Science Foundation.)

Everyone seems to be involved in science education reform: teachers and scientists, parents and employers, educational researchers and engineers, federal and state government agencies, school boards and students. We talk about "stakeholders" in the reform process and, of course, we now realize that we are all stakeholders in this process.

Despite the many voices, there is some consensus on what we have to do to reform the system to reach world-class standards. And, as the National Science Education Standards (NSES) make clear, this does not just involve changing what we teach, but how we teach, how we prepare teachers, and how we measure the success of our efforts with students, teachers, schools, and school systems. We do seem to understand that we need to make changes throughout the educational system to implement sustainable reform.

However, although we all apparently recognize that reform means more than changing the content of our textbooks, we spend a disproportionate amount of time discussing science content when we talk about reform. We do not spend as much time talking about the resources that are needed to implement the student-centered, hands-on, inquiry-based learning that is the keystone of the NSES. This is not just an issue that receives less attention than curriculum reform; it is an issue that, unless addressed directly, will doom reform efforts to failure.

The NSES address the issue of resources in the program and system standards, found at the end of the standards document (NRC, 1996). There are six program standards, the fourth of which, Program Standard D, relates to resources:

The K-12 science program must give students access to appropriate and sufficient resources, including quality teachers, time, materials and equipment, adequate and safe space, and the community.

- The most important resource is professional teachers.
- Time is a major resource in a science program.
- Conducting scientific inquiry requires that students have easy; equitable, and frequent opportunities to use a wide range of equipment, materials, supplies, and other resources for experimentation and direct investigation of phenomena.
- Collaborative inquiry requires adequate and safe space.
- Good science programs require access to the world beyond the classroom.

System Standard D states, "Policies must be supported with resources."

Resources for Reform

Professional Teachers
The need to hire well-prepared teachers and the need for districts to budget for teacher continuing professional development are both recognized in NSES system Standard D. What is not explicitly mentioned is the need for *more* science teachers, nor is any indication given of where they will be found.

In 1994, nationwide, 95+% of high school students took Biology 1, 51% took Chemistry 1, and 22% took Physics 1 (Blank and Gruebel, 1995). Since we are already anticipating a serious shortage of qualified science teachers, who will be teaching more science courses to more students? The solution is certainly not to cram more and more students into the same class. Matti and Weiss (1994) reported that the average high school science class size was 23 students nationwide, and 11% of science classes contain more than 30 students. The overcrowding varies considerably from state to state—for example, the percentages of all science classes in grades 9-12 that contain 30 or more students are 27% in California, 42% in Utah, 21% in New York, and 5% in Texas. Overcrowding certainly does not encourage teachers to let students out of their seats to do science.

There is also the issue of the aging teacher population, which hits at both the elementary and secondary levels with the prospect that demand for replacement teachers may exceed supply early in the next century. In 1971, more than 33% of all elementary and secondary school teachers were under 30 (Matti and Weiss, 1994). Twenty years later, 10% of all these teachers were younger than 30. Who will be teaching science in 2061?

Of course, should all students be required to receive more science instruction, there is the very real possibility that, at the middle and high school levels, more teachers will teach out of their specialty. Even in states with well-prepared science teachers, there is teaching out of field. The worst-case scenario is usually described as the chemistry teacher taking the physics class, the biology teacher taking chemistry, and the biology being taught by the coaching staff. This situation could get much worse!

None of the above comments relates to either how well prepared teachers at the elementary and secondary level are to teach science or how accepting they are of the reform agenda. Nor do they address the issue of how much in-service development must be provided to help teachers implement standards-based reform. Recent data indicate that, prior to release of the NSES, only 23% of grades 1-4 teachers, 34% of grades 5-8 teachers, and 56% of grades 9-12 teachers had received more than 15 hours of in-service education over a three-year period (Weiss et al., 1994). Data also indicate that, although teachers may be aware of certain reform issues, they may not feel comfortable enacting some of the reforms. This is particularly true at the high school level where, for example, only 59% of science teachers support the teaching of fewer concepts in greater depth (a fundamental principle of curriculum reform) compared with about 69% at the K-8 level (Weiss et al., 1994). Another example: Although 96% of teachers in grades 1-4 and 93% of teachers in grades 5-8 support teaching science to every student every year, the support drops to 76% for teachers in grades 9-12.

It seems that a cadre of high school teachers will have difficulty with the notion of "science for all." All of us involved in science education reform have heard the plaintive cry, "But you don't really mean *all*, do you?" Again, the data are not particularly encouraging. While the NSES support high-quality, hands-on, inquiry-based science instruction for all students, high school teachers have reported different objectives for low- and high-ability students; and 68% of them support ability tracking (Weiss et al., 1994). Low-ability students are less likely than high-ability students to be in classes that emphasize reasoning/inquiry skills (66% vs. 92%, respectively).

It is also depressing to learn that low-ability students are less likely than high-ability students to be in classes that emphasize "hands-on" science (56% vs. 68%) and more likely to be asked to read from a book (55% of classes vs. 40%). This is odd since the lower ability students may need more hands-on concrete experiences than the higher ability students in order to learn abstract science concepts (Ware, 1992). If students are being denied hands-on science experiences because some of them may present a discipline problem, asking these students to learn science by reading the text is going to improve neither their science achievement nor their behavior.

Substantial resources for professional development will have to be made available to persuade teachers to implement science education reforms that they may actively oppose or subconsciously reject. It is not just an issue of ensuring that teachers know the science and the pedagogy, it is also an issue of the teacher's beliefs about who can and who cannot learn science and their feelings about what it means to be a "good" teacher. Changing entrenched values takes plenty of time and money.

Time

One of the most crucial and problematic resources for science is time: time on the schedule for science instruction; time for hands-on, inquiry-based science; and time for teachers to interact with one another during the school day.

Time on the schedule. Working in a scientific community, it is easy to fool ourselves into believing that all Americans think that science is a basic subject that should be taught to all students every year from K to 12. What is actually happening now? Nationwide, on average, students in grades 1-3 spend 24 minutes per day learning science; in grades 4-6 the average rises to 36 minutes per day (NSF, 1996). From 1977 to 1993, we added, on average, seven minutes of science a day in grades 1-3 and eight minutes a day in grades 4-6. Where is the time to be found on the elementary school schedule to implement standards-based science reform?

Ten states require three science credits for high school graduation, thirty states require two science credits, two states require either two or three science credits (with three or two mathematics courses), two states require one science credit for high school graduation (!), and the remainder leave the decision to the local education authorities (Blank and Gruebel, 1995). Why are high school students not pressured to take four years of science in order to obtain a high school diploma? Could it be that science is not really considered a basic subject after all?

At the high school level, the 45- or 50-minute laboratory period is a notorious barrier to the innovative laboratory session. You cannot do very much in that period once you allow time for pre-and postlab activities and cleanup. Some school districts are moving to double periods or even block scheduling, which certainly facilitates the introduction of meaningful laboratory activities. It also means that some teachers will need help to find and/or develop new laboratory activities and to adapt to new strategies for time and class management.

Does the reform of science education, grades K-12, necessarily mean that more time must be found on the schedule for science? Can existing time be better organized? Reading the NSES, it is difficult not to conclude that a greater proportion of the school day, at all grade levels, will have to be found if we are to address the standards. But there are standards being developed for subjects other than science. *All* disciplines will be making the case for more time on the schedule.

Time to do hands-on science. Several years ago, Lee Marek, a very talented high school chemistry teacher from Illinois, wrote an editorial for *Chemunity News* on the subject of the importance of time to the science teacher (Marek, 1995). Here are some of his extremely pertinent comments:

> Twenty years ago I was teaching alone in my classroom. The football coach was on the field alone with his team. Now he has an offensive line coach, receiver coach, trainer, athletic director (with secretary), and assistant director. I am still alone in my science room, but now I need to know computers and laser disc technology, know how to write across the curriculum, teach thinking skills and math skills, worry about safety and disposal like I never have before, facilitate cooperative learning, and handle mainstreaming.

Across the country, states and large cities are strongly promoting hands-on, inquiry-based science without providing teachers with the time they need to implement it. The NSES address this issue as follows:

> The emphasis on the need for professional teachers of science does not diminish the need for other school personnel who enhance the science program. In addition to an administrative team and teaching colleagues, other support personnel might include the resource librarian, a laboratory technician, or maintenance staff.

I grew up in Great Britain. From the ages of 11 to 18, I attended a girls' grammar school run by the local education authority (i.e., public education, not "public school" education). There were approximately 550 girls in the school. The science staff were supported by five certified laboratory technicians: one each for chemistry, physics, biology, physical geography, and general science. At least two of these technicians worked full time. All of our sciences were taught as laboratory-based courses; the people resources were there, so the teachers had time to do this.

This school wasn't unique in its use of laboratory technicians; their use was and is the norm in the United Kingdom and in most of the developed world. Even developing countries seem to find the money to pay for a laboratory technician to support science teaching staff in secondary schools. Why is this an odd idea in the United States? Laboratory instruction needs preparation time—time that most of our teachers do not have—for setup, solution preparation, stockroom maintenance, equipment construction and repair, and so forth. Teachers should not have to depend on the services of a student, trained by the teacher after school, in order to introduce a laboratory activity (although many teachers enjoy training students to provide this support).

At present, teachers report that they spend 26% of class time using hands-on manipulative activities in grades 1-4, 23% in grades 5-8, and 21 % in grades 9-12 (Weiss et al., 1994). Is this the appropriate level of practical instruction according to the standards? Perhaps if teachers were not teaching six periods a day and taking on other duties for the seventh period, they might manage to include more hands-on instruction, even without a laboratory technician.

Time to interact. The teacher's crowded daily schedule also contributes to a sense of isolation. The NSES recognize the importance of teachers functioning as members of a community of learners in both the professional development standards and the program standards:

> Regular time needs to be provided and teachers encouraged to discuss, reflect, and conduct research around science education reform. ...Time must be available for teachers to observe other classrooms, team teach, use external resources, attend conferences, and hold meetings during the school day.

Table 16.1
Percentage of Science Teachers Indication Problems with Resource Availability

Resource	Grades 1-6			Grades 7-9			Grades 10-12		
	1977	1986	1993	1977	1986	1993	1977	1986	1993
Materials to individualize instruction	30	30	30	27	27	37	28	20	38
Funds for equipment and supplies	29	30	40	24	26	31	27	23	36
Access to computers	—	18	20	—	23	37	—	17	40

Source: NSF, 1996

It is sobering to compare the conditions under which Japanese science teachers work with conditions here in the United States. Typically, Japanese 8th-grade science teachers teach 18 periods a week, compared with the U.S. average of 25 (NCES, 1996). The Japanese teachers each have a desk in a large teachers' room where they spend most of their time, when not actually instructing, sharing information about students, educational strategies, and the curriculum.

In the United States, even when teachers have a period for class preparation during the day, there is a fair chance that their science colleagues will be in class. This compounds the difficulty of team planning and cooperation. The same situation exists in the school at large. Because of supervision and extracurricular assignments, it may be impossible for a typical school staff to all meet together regularly. In the United States, only 16% of science teachers in grades 9-12 agreed with the statement

"I have time during the school week to work with my peers on science curriculum and instruction." Only 14% of teachers in grades 1-8 agreed with that statement (Weiss et al., 1994).

Table 16.2
Schools Reporting Insufficient Capability to Support Technology

Technology	% Of All Schools	No. Of Schools	No. Of Students
Fiber-optic cable	86.8	66,000	35.4
Phone lines for instructional use	61.2	47,000	24.8
Conduits for computer/computer network cables	60.6	46,600	24.9
Modems	57.5	44,200	23.0
Phone lines for modem	55.5	42,700	22.5
Computer networks for instruction	51.8	40,100	20.7
Electrical wiring for computers	46.1	35,700	19.3
Electrical power for computers	34.6	26,800	14.5
Laser disc player/VCR	33.5	25,700	13.5
Cable TV	31.7	24,200	12.2
Computer printers for instruction	29.3	22,700	11.9
Computers for Instruction	25.2	19,500	10.3
TVs	15.9	12,200	6.8

Giving science teachers (or any teacher, for that matter) significant amounts of time to interact during the school day seems impossible within our system. It would clearly involve (again) hiring more teachers to reduce the load on those already employed. The financial resources to do this just are not available.

The need for teachers (all teachers, not just science teachers) to be given time to implement educational reforms is becoming a more visible issue. Adelman and Walking Eagle (1997) have described the teachers' need of time to learn about and practice innovations, introduce and institutionalize reform, and reflect and improve upon reforms. In a recent study of how teachers use time in the context of reform, they concluded that while it takes time to implement change in the classroom, time is a necessary commodity that "more often than not is given short shrift."

Some schools are beginning to address this issue by building time into the weekly school schedule to allow teachers to plan and work together. Students may arrive late or leave early so that all teachers are available for group activities and cooperation.

Access to Equipment and Supplies
Science teachers need access to equipment, consumable supplies, computers, and the Internet. Not only is access to these resources considered a problem for about 36% of all teachers (see Table 16.1), but access to all kinds of equipment is more likely to be a problem for classes with 40% or more of minority students than for other classes (NSF, 1996).

Weiss et al. (1994) report that the median amount spent on consumable science supplies is $0.51 per student per year at the elementary school, $0.88 at the middle school, and $2.22 at the high school. Compare this with the amount that teachers report spending out of their own pockets each year. Elementary teachers report spending $80 of their own money for science and mathematics each year; high school teachers report an average of $250 out-of-pocket spending for five classes per year. Now there's a way to run a business—get the employees to buy their own supplies! Presumably, as more hands-on science is introduced at all grade levels, the cost of consumables is going to rise. This should not mean that more teachers must take more money out of their own pockets to ensure that their students have an opportunity to meet international standards of excellence. Note that the annual average salary of all U.S. teachers in 1995-1996 was $37,643 (Nelson and Schneider, 1996).

Adequate and Safe Space
In 1995, the General Accounting Office examined the physical condition of school facilities across the nation, looking at safety issues and whether the schools were able to meet "the functional requirements of some key education reform activities."

Some 42% of elementary and secondary schools (32,100 schools enrolling 14.6 million students) indicated that they did not meet the functional requirements for conducting laboratory science at all well (GAO, 1995). Where the school enrollment exceeded 50.5% minority students, 49.1% of schools reported they were "not at all" well prepared to teach laboratory science. In eight states, more than 50% of schools were unprepared to teach laboratory-based science.

Science classes require laboratory benches, water, electrical power, gas and vacuum outlets, adequate ventilation, and safety equipment. In Chicago, officials reported that only 25% of their schools were ready for laboratory-based instruction. New Orleans schools were especially concerned about safety issues, and this is a problem for most large cities.

Access to the World beyond the Classroom

A very important message conveyed by the NSES is that science exists in the world beyond the classroom; science does not just take place at the traditional laboratory bench. This message is reflected in the selection of content in the standards, which includes science and technology in society as well as the development of an understanding of risk-benefit analysis. Regrettably, for the past 30 years, there have been few examples in U.S. science curricula of the applications of science. In chemistry, for example, industrial chemistry has all but disappeared, except in textbooks such as *ChemCom.*

Students need to get out into the community—into hospitals and forensic laboratories, wastewater treatment plants and petroleum refineries, and textile mills and bakeries. This is becoming more and more difficult for logistical, insurance, and cost reasons; but it is certainly possible for the community—for employees in business and industry—to come to the schools. Of course, all school visitors should communicate with the teachers of the classes they are visiting so that the visits become value added to the lesson, not merely an interruption of an already tight schedule.

Modern technology facilitates access to the world beyond the classroom. Here again, our schools are not well positioned to take advantage of the available technology. The infrastructure of many schools will not permit them to take advantage of the computer and the vast resources of the Internet (see Table 16.2).

A Question of Priorities

Someone once said that education is everyone's second priority. Sometimes, it seems that science education is the third on the list. Certainly, resource issues will not be solved in the time-honored way by "throwing money at the problem." However, try *not* throwing *any* money at the problem, and the problem remains.

Nationally, we need to get the message across to all the American people, not just to the education community, that science really is a basic subject that should be made accessible to all students for every year of compulsory education. There is an essential marketing job to be done here; it may be accomplished by the efforts of companies or individuals working for those companies, by politicians, by school boards, by teachers, by movie stars. Until the American public recognizes the vital importance of science, mathematics, and technology education to children who will be learning and earning in the twenty-first century, educational systems will be slow to redirect or find new resources for science education reform. Parents who now hold bake sales for football equipment must somehow get just as committed to running bake sales for science and computer equipment. (The latter does happen, but not often enough.)

Industry can help make the case, at all levels of government, that all educational reform takes resources, and one of the most important of these resources is time. The case has to be made, school board by school board, that world-class science education standards will not be met without adequate resources, including the provision of time and resources for the science teacher to teach hands-on, inquiry-based science. Here is a national goal that science teachers could really respond to: By 2000, every school science department will have at least one full-time laboratory technician.

Finally, reform itself takes time, and neither the general public nor politicians are especially patient. We must all stay the course of these reforms, no matter how long it takes. Even if it takes longer than the year 2061 (see AAAS, 1993), we must continue to strive for reform—there is no possible direction but forward if the twenty-first century is to belong to the United States in the same way as the departing century.

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