#618

7. Chem: (39%) The average molecular weight of chlorine is 35.45 g/mol. What percent is the isotope weighing 35.00 g/mol and what percent is the isotope weighing 37.00 g/mol?
   Lang: (59%) The average amount spent on a class ring was $163 per student. What percent of the students in the class spent $100 and what percent spent $200?
   Math: (86%) $400(x) + 15(1 - x) = 190$ What is x?

8. Chem: (41%) $2Al + 3H_2SO_4 \rightarrow Al_2(SO_4)_3 + 3H_2$
   How many moles of hydrogen gas are produced when 4 mol aluminum reacts with 12 mol sulfuric acid?
   Lang: (92%) Three oranges and two apples are required for each fruit basket. How many complete fruit baskets can be made if we have nine dozen oranges and eight dozen apples?
   Math: (58%) $3x \geq 108$ *and* $2x \geq 96$
   What is the smallest possible value of x?

9. Chem: (50%) One mole of a reactant reacts spontaneously to form products in 2 ns. How many molecules react per second?
   (1 mol of molecules = 6.02×10^{23} molecules)
   (1 ns = 1×10^{-9} s)
   Lang: (75%) (a) In Michigan, 1.4×10^5 dozen eggs are collected every day. How many individual eggs are laid each hour?
   (91%) (b) Dunkin Donuts sells 200 dozen doughnuts every day. How many individual doughnuts do they sell each hour?
   Math: (72%) $\frac{1.08 \times 10^{12}}{5.4 \times 10^{-7}} = y$. What is y?

10. Chem: (67%) A 6.0 M solution of HCl is diluted from an initial volume of 1.0 L to 3.0 L. What is the final concentration?
   Lang: (93%) Initially there is ½ cup sugar in 1 qt of applesauce, but 2 qt unsweetened applesauce are added. What is the final concentration of sugar per quart of applesauce?
   Math: (95%) $\frac{6}{4y} = \frac{x}{y}$ If $y = 4$, what is x?

Achieving Chemical Literacy

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A week prior to graduation at a major American university 25 seniors, selected at random, were asked a simple question: "What is the difference between an atom and a molecule?" Only a third of the students queried could answer the question correctly. Even allowing for the festive mood of the graduates, this result does not give much confidence in the ability of America's education system to turn out students who are in command of rudimentary facts about their chemical environment.

There can be little doubt that we are faced with a generation of Americans who complete their education without learning even the most basic concepts about chemistry. These citizens lack the critical knowledge to make informed decisions regarding environmental issues, resource management, and research funding. Basic chemical knowledge about atoms, bonding, the chemicals of life, and the rich variety of materials that surround us are rarely covered in the core college curriculum. With the exception of science majors, therefore, college graduates receive little of this basic knowledge.

We believe that two problems pervade the organization and presentation of science for nonscience majors in American colleges and universities:

(1) Almost all science courses, even for first-year students, are geared toward science majors. Such courses do little to foster scientific literacy among nonscience majors.

(2) Science courses rarely integrate physics, chemistry, geology, and biology. Students must, therefore, take courses in at least four departments to gain a basic level of literacy in the physical and life sciences.

A number of successful departmental-oriented courses have been proposed to address the first problem[2-4]. Yet most of these efforts examine only one branch of science. In short, the science curricula of most colleges and universities fail to provide the basic science education that is necessary to understand the many science and technological issues facing our society.

In an effort to combat the steady deterioration of science literacy in the United States, we have developed a course for undergraduate nonscience majors at George Mason University. The University's Science Core Committee has recommended that all nonscience majors should take this course, followed by a departmental laboratory and lecture course in physics, chemistry, geology, or biology. The objective of this article is to rationalize the approach and content of our course, "Great Ideas in Science", and to outline the chemistry component of that offering.

The Need for Science Literacy

What should nonscience majors know about science when they graduate? We think that at a minimum they should be able to place important public issues about the environment, medical advances, government support of research, and new materials and technologies in a scientific context. They should be able to read and appreciate popular accounts of major discoveries in physics, chemistry, geology, and biology. And they should understand that there are a few universal laws that describe the behavior of our physical surroundings—laws that operate every day, in every action of our lives.

Nonscience majors do not need to become scientists to understand what scientists do and why they do it. They do

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not have to be able to calculate the orbit of a comet, or synthesize a superconductor, or sequence a section of DNA to understand why comets, superconductors, and genes are fascinating and important things to study. We need to develop courses that minimize scientific jargon and mathematical techniques, while emphasizing the general principles of science. The guiding philosophy behind our syllabus is simple: what does a student *need to know* to function as a scientifically literate adult?

The traditional academic response to this line of reasoning is the sporadic appearance of departmental courses with catchy titles like "Physics for Poets". We support these efforts, but with one major reservation. It is well and good for chemistry departments to offer "Chemistry for Poets", but will those students graduate with a basic knowledge of the other sciences? If a rival "Geology for Poets" course lures students away from chemistry, will the graduates be scientifically literate? The obvious solution is for science departments to work together to create an integrated overview of scientific knowledge, rather than these more specialized presentations.

We define scientific literacy as the knowledge you need to understand the scientific component of public issues. This knowledge includes a mix of facts, vocabulary, concepts, history, and philosophy. The core knowledge changes gradually with time, in contrast to the constantly shifting scientific and technological issues in the news. Most important, the knowledge is not the specialized stuff of the experts, but the more generalized background used in political discourse. If students can take newspaper articles about genetic engineering, the ozone hole, or chemical waste and put them in a meaningful context—if they can treat news about science in the same way they treat news about business, government, and sports—then they are scientifically literate.

Course Organization

To achieve the goal of scientific literacy, students must be presented with a variety of knowledge. Of first importance, science is organized around a few core concepts—pillars that support the entire structure. These laws and principles account for everything we see in the world around us. Since there are an infinite number of possible observations and only a few laws, the logical approach in a general science course is to begin by emphasizing the basic principles—call them laws of nature or great ideas, if you like. These few principles form a seemless web of knowledge that binds all scientific knowledge together. The first few weeks of the course are devoted to matter, energy, forces, and motion—the concepts that reappear over and over in any discussion of the physical universe. They are absolutely essential to understanding science—you can no more learn genetics while ignoring the laws of thermodynamics than you can study language while ignoring verbs.

Once the basic concepts that unify all science have been presented, the course moves on to look at specific systems—subsets of the matter and energy that make up our universe. We have adopted a traditional grouping of physical, earth, and life sciences. In each of these categories, the presentation is organized around another set of great ideas appropriate to that field.

The list of great ideas is neither obvious nor immutable. Any scientist could come up with a compilation of 20 or so key concepts. Compare a dozen different lists and eight or 10 of those ideas will appear just about every time. Newton's laws of motion, the laws of thermodynamics, Maxwell's equations, and the concept of the atom are basic to all disciplines, for example. After much thought and revision we have proposed a list of 19 great ideas (table). This list is not sacred, but it does serve as a useful starting point for a discussion of curriculum.

In chemistry, for example, three themes—the atom (matter is made of atoms), chemical bonding (atoms are bound by electron glue), and properties of materials (the way a material behaves depends on how its atoms are arranged)—provide a framework for much of the research and study undertaken in the 1990's. These three concepts unify much of what we know about our chemical surroundings, but at the same time they relate to the basics principles about matter and energy contained in the first few weeks of the course. In addition, key concepts of nuclear chemistry, geochemistry, and biochemistry are integral aspects of later units. By the time students complete the course, they not only have a general introduction to the nature and significance of chemicals, but they also have specific knowledge about the unique chemical character of specific systems (the continents, for example, or cells).

Great Ideas in Science

1. The Scientific Method: The universe is regular and predictable.
2. Forces and Motion: One set of laws describes all motion.
3. Energy: Energy is conserved and always goes from more useful to less useful forms.
4. Electricity and Magnetism: Electricity and magnetism are two aspects of the same force.
5. The Atom: All matter is made of atoms.
6. Quantum Mechanics: Everything comes in discrete units, and you cannot measure anything without changing it.
7. Chemical Bonding: Atoms are bound by electron glue.
8. Atomic Architecture: The way a material behaves depends on how its atoms are arranged.
9. Nuclear Physics: Nuclear energy comes from the conversion of mass.
10. Particle Physics: Everything is really made of quarks and leptons.
11. Astronomy: All stars form in space and eventually burn out.
12. Cosmology: The universe was born at a specific time in the past, and it has been expanding ever since.
13. Relativity: Every observer sees the same laws of nature.
14. Plate tectonics: The surface of the earth is constantly changing.
15. Earth Cycles: The earth operates in many cycles.
16. Cellular and Molecular Biology: All living things are made from cells, the chemical factories of life.
17. Genetics: All life is based on the same genetic code.
18. Evolution: All life evolved by nature selection.
19. Ecosystems: All life is connected.

It is instructive to consider great ideas in chemistry that were *not* included in our list. We have polled a number of chemistry department colleagues about their own perceptions of the key ideas in their science. In addition to the atom, bonding, and material properties, which appeared most frequently, the following potential great ideas were proposed:

1. Chemicals can react to form new compounds.
2. Chemical reaction rates depend on many factors.
3. Atoms are neither created nor destroyed in chemical reactions.
4. Materials change character through phase transitions.
5. Carbon plays a unique role in the chemistry of life.

We agree that each of these statements represents an important idea in chemistry, and each is discussed in our curriculum. Statements 1 through 4, for example, all relate to aspects of chemical reactions and phase transitions that are recurrent themes in discussions of bonding and material properties. Statement 5 on carbon's unique role is emphasized in the unit on biochemistry. Our choices of the most significant concepts in chemistry may differ from those of other teachers, but the great ideas approach has the advantage that selection of one set of ideas in no way limits the ability to focus on other important concepts.

The great ideas approach has another tremendous advantage for students and teachers. Any issue of scientific or technological importance can be introduced by way of illustrating general principles. We frequently use examples from recent newspapers: novel materials, biochemical effects of drugs, and environmental concerns. It is entirely possible that issues that loom large today—AIDS, drugs, the ozone hole—may seem insignificant in a few years, while new is-

sues will undoubtedly take their place. Each teacher can choose examples to suit his or her interests and style, but the underlying principles will remain nearly the same from year to year.

Another benefit of the "great ideas" format is that many important scientific ideas and technological fields are not well represented by any one traditional science department: computers and information technology, brain research and medical science, and science versus nonscience are a few of the subjects that are included by illustration and example throughout the course. Newton's laws of motion are examples of core ideas in science, but students should also know when Isaac Newton lived, how he incorporated the earlier work of Galileo and Kepler, and how his work influenced the philosophy of the Enlightenment. Newton's laws can be illustrated with such practical examples as why you should wear a seat belt, the launch of the Space Shuttle, or the differences between football linemen and quarterbacks. Newton also provides a good point to discuss the relationship between science and technology, the importance of experiments in science, and the scientific method.

Implementing the Course

Perhaps the most frequently voiced objection to our course is "No one will be able to teach it." Such a criticism, in itself, is a serious indictment of our scientific education system. If professional science educators are unwilling to learn the most basic principles of other fields, or uninterested in such knowledge, how can we expect nonscientists to gain any level of science appreciation? If physics teachers refuse to learn about biochemistry or biologists shun plate tectonics, why should students care about these subjects?

Ideally, one faculty member should teach the entire course. We have found many faculty members at George Mason University who are eager to participate in the effort. During the spring 1990 semester, eight junior and senior faculty members representing physics, chemistry, geology, and biology departments attended the course and are now ready to teach it themselves. None of us are experts in all the fields covered, and students' questions often leave us stumped. But it provides a valuable lesson to the class when a teacher actually says, "I don't know the answer, but I'll try to find out." What better way to emphasize that learning is an ongoing process?

An obvious alternative is to have several faculty members teach their own disciplines; thus chemists, geologists, and biologists could stay close to their own turf. We discourage such an approach, however, for several reasons. One key theme of the course—that the sciences form an integrated, seamless web of knowledge—is lost. Furthermore, specialists tend to slip into confusing jargon and dwell on unnecessary detail, thus defeating the purpose of the overview. Finally, students may well ask why they must master a range of scientific topics when the faculty members appear unwilling to do so.

Student Response

"Great Ideas in Science" has been taught at George Mason University for four semesters, during which time more than 200 student evaluations have been obtained. Students were asked to comment on the content, presentation, fairness in testing, and other aspects of the course. The only recurrent objection—raised by more than half of the students—was the lack of a suitable course text. This problem has recently been remedied.[5]

The overall student reaction has been extremely positive, placing the course in the top 10% of University offerings in content and presentation. Nonscience students remarked that it was first time a science course seemed relevant to their everyday lives, while science majors (as many as a quarter of those taking the course) commented that it was the first time they had thought about the different sciences as part of an integrated system of knowledge.

All but a few students felt that grading was fair, even though nonscientists and science majors took the class together. Student grading is based primarily on tests with a mixture of multiple choice, true–false, and essay questions. Tests stress concepts rather than vocabulary or facts. For example, the first quiz, taken in the fifth week following lectures and demonstrations on laws of motion, thermodynamics, and electricity and magnetism, consists of a video of springboard divers and a frisbee game *played backward*. Students recognize that certain actions violate their intuition about the physical world, and they are asked to explain which of several laws were violated by the reversed film.

Each student must also write a term paper on some aspect of science and society (for example, "Should we build the SSC?" or "How serious is the radon problem?"). A business major wrote on Japanese versus United States corporate research strategies, an education major wrote on what is wrong with American science education, and a nursing major wrote on the health risks of pesticides. The term paper thus allows each student to integrate science with his or her major.

Conclusions

Great Ideas in Science has been a stimulating course to develop and a rewarding one to teach. As specialists in experimental mineralogy and theoretical physics, we have had the chance to see our specialties in a broader scientific context. Dozens of students who were scared of science, or just plain bored by it, have come away with a new appreciation for their physical universe and their place in it. We encourage our colleagues in other colleges and universities to develop similar offerings, and to help all our students achieve scientific literacy.

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[5] Hazen, R. M.; Trefil, J. *Science Matters: Achieving Scientific Literacy*; Doubleday: New York, 1991.