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Achieving Geological Literacy*

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ABSTRACT

The course "Great Ideas in Science" was developed for undergraduate nonscience majors at George Mason University in response to concerns about the scientific illiteracy of most graduates. The course emphasizes a few key overarching concepts in physics, chemistry, geology, and biology in order to introduce students to the essential aspects of science without getting involved in the complex vocabulary or rigorous mathematical derivations. Key earth-science ideas, for example, include plate tectonics, earth cycles, and evolution. This approach is advantageous because it incorporates and integrates ideas in several sciences, it fosters an appreciation of science as an ongoing process, and it encourages the use of current events as illustrations of general principles.

Keywords: Education – science; education – undergraduate; earth science – teaching and curriculum.

Introduction

At the 1987 commencement of Harvard University, a film maker carried a camera into the crowd of gowned graduates and, at random, posed a simple question: "Why is it hotter in summer than in winter?" The results, displayed graphically in the film *A Private Universe*, were that only 2 of the 23 students queried could answer the question correctly. Even allowing for the festive atmosphere of a graduation ceremony, this result doesn't give much confidence in the ability of America's most prestigious universities to turn out students who are in command of rudimentary facts about their physical world.

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 their planet. These citizens lack the critical knowledge necessary to make informed decisions regarding geological hazards, environmental issues, resource management, and research funding. Global concepts of plate tectonics and the cycles of rock, water, and the atmosphere are rarely covered in the core college curriculum. With the exception of earth-science majors or those students who happen to take an introductory geology course, therefore, college graduates are exposed to 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.

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 Science Core Committee at George Mason University has recommended that all nonscience majors take this course, and that they follow it with a two-semester laboratory and lecture course in physics, chemistry, geology, or biology. The objective of this article is to explain the approach and content of our course, "Great Ideas in Science," and to outline the earth-science 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 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 apply to 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 don't 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 geology departments to offer "Geology for Poets," but will those students graduate with a basic knowledge of the other sciences? If a rival "Biology for Poets" course lures students away from the earth sciences, 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 one needs 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

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: Everything is made of atoms.
6. Quantum Mechanics: Everything comes in discrete units, and you can't 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: Stars live and die.
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: Everything on earth operates in 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 natural selection.
19. Ecosystems: All life is connected.

Table 1. Great Ideas In Science

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 nuclear 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 is 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 seamless web of knowledge that binds all scientific knowledge together. The first few weeks of the course are devoted to matter, energy, forces, and motion, and the concepts relating them that reappear over and over in any discussion of the physical universe. They are essential to understanding science. One can no more learn genetics while ignoring chemistry than 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 twenty or so key concepts. Compare a dozen different lists and eight or ten 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 1). This list is not sacred, but it does serve as a useful starting point for a discussion of curriculum.

In the earth sciences, for example, two key ideas provide the framework for much of the research and study undertaken in the 1990s. The first of these great ideas – plate tectonics – has to do with global changes of the planet in response to heat generated in its deep interior. The second idea – Earth cycles – focuses on cycles of rock, water, and wind as mechanisms for change on the earth's outer layers. These two great ideas unify much of what we know about the earth, but at the same time depend on the deeper principles discussed in the first few weeks of the course. By the time students complete the course, they not only have a general notion of how our planet works, but they will also have specific knowledge about how individual pieces of it (the continents, for example, or the North American jet stream) operate. In addition, key concepts of mineralogy are included in the unit on properties of materials, while paleontology and historical geology play a central role in the section on evolution.

It is instructive to consider great ideas in the earth sciences that were not included in our list. We have polled a number of earth-science colleagues about their own perceptions of the key ideas in our science. In addition to plate tectonics, the rock cycle, and evolution, which appeared most frequently, the following potential great ideas were proposed:

1) The earth is billions of years old; most geological changes occur slowly over very long periods of time.
2) Younger rocks superpose on older rocks.
3) The climate of the earth changes significantly over time.
4) The structure of the earth is layered with core, mantle, and crust.
5) Earth is a planet that orbits the Sun, a star.

We agree that each of these statements represents a key idea in the earth sciences and each is discussed in our curriculum. Statement 1 about gradualism and the earth's great age, for example, is central to descriptions of plate tectonics, rock cycles, and evolution. Statements 2 and 3 describe important aspects of earth cycles, statement 4 is an integral part of the presentation of plate tectonics, and statement 5 is covered in both the unit on Newton and the unit on stars. Our choices of the most significant concepts in geology 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: space shuttle missions, earthquakes or volcanoes, new products, and current health 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 issues 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 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 one should wear a seat belt, the launch of the space shuttle, or the differences between football linemen and quarterbacks. Newton also provides a basis for discussing 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 that no one person will be able to teach it. Such a criticism, in itself, is a serious indictment of our science-education system. If professional science educators are unwilling to learn the most basic principles of other fields, or are uninterested in such knowledge, how can we expect non-scientists to gain any level of science appreciation? If physics teachers refuse to learn about genetics 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 the physics, chemistry, geology, and biology departments attended the course and are now ready to teach it themselves. None of us is an expert in all the fields covered, and student 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 geologists, chemists, 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.

Conclusions

Great Ideas in Science has been an enriching course to develop and a rewarding one to teach. As specialists in 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.

About the Authors

Robert Hazen and James Trefil are Clarence Robinson Professors at George Mason University, where they teach scientific literacy. Hazen, also a researcher at Carneigie Institute's Geophysical Laboratory, received earth-science degrees from MIT and Harvard. He has written 150 articles and 7 books on earth and materials science, including *The Breakthrough, The Poetry of Geology*, and *Weather Inexhaustible.* Physicist James Trefil, in addition to more than 100 professional papers, is author of a dozen books on science including *The Moment of Creation, A Scientist at the Seashore, Meditations at 10,000 Feet,* and as coauthor, *The Dictionary of Cultural Literacy.* Hazen and Trefil's latest book, *Science Matters: Achieving Scientific Literary,* is published by Doubleday.

Food for Thought

Scientific literacy – which encompasses mathematics and technology as well as the natural and social sciences – has many facets. These include:

[1] being familiar with the natural world and respecting its unity;
[2] being aware of some of the important ways in which mathematics, technology, and the sciences depend upon one another;
[3] understanding some of the key concepts and principles of science;
[4] having a capacity for scientific ways of thinking;
[5] knowing that science, mathematics, and technology are human enterprises, and knowing what that implies about their strengths and limitations; and
[6] being able to use scientific knowledge and ways of thinking for personal and social purposes.

American Association for the Advancement of Science, 1989, Science for all Americans — A Project 2061 report on literacy goals in science, mathematics and technology: *American Association for the Advancement of Science*, Washington, D.C., 217 p. (from p. 20).