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Point of View

By Robert M. Hazen and James Trefil

General Science Courses Are the Key to Scientific Literacy

IT IS NO SECRET that the average college graduate is scientifically illiterate. Dozens of studies document the sorry story with examples of students who don't know the difference between an atom and a molecule or can't explain why there are four seasons. We are turning out graduates who can't understand the simplest science-related newspaper article.

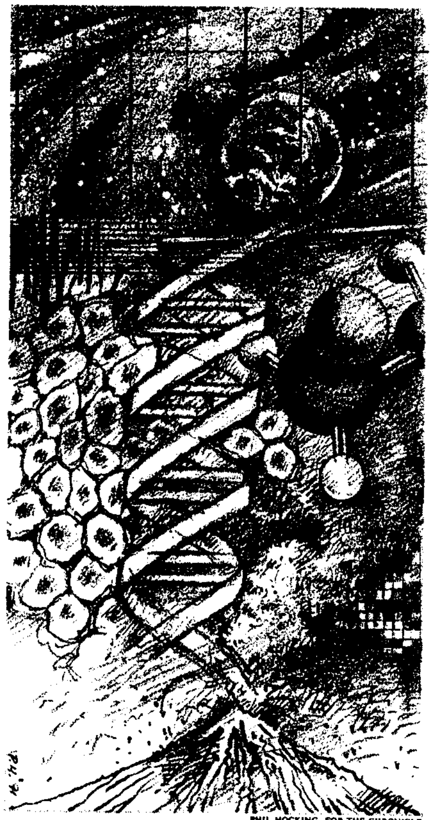
The debate over what to do about this crisis has been confused by the lack of a clear definition of scientific literacy. Many scientists believe the problem would be solved if more students majored in science. But that view ignores the vast majority of Americans who have no intention of becoming professional scientists. For them, scientific literacy has nothing to do with knowing how to sequence DNA, synthesize a superconductor, or map a geological fault. What non-scientists do need is the background to grasp and deal with matters that involve science and technology. It is this ability to understand science in its day-to-day context that we propose to call scientific literacy.

Most societal issues concerning science and technology require a broad range of knowledge. To understand the debate over the disposal of nuclear waste, for example, one needs to know how nuclei decay to produce radiation (physics), how radioactive atoms interact with their environment (chemistry), how radioactivity from waste can enter the biosphere (earth science), and how it will affect living things when it does so (biology). Other issues, such as global warming, space research, and alternative energy sources likewise depend on a spectrum of scientific concepts, although clearly more than just science is involved. The scientifically literate non-scientist needs to understand a little bit of several disciplines to cope with such issues. Scientific literacy thus is a grasp of an eclectic mix of facts, vocabulary, and principles. It is not the specialized knowledge of the experts, nor does it rely on jargon and complex mathematics.

In college, most non-science majors are required to take one or two science courses, at most. Not surprisingly, they usually select the offering that has the least threatening reputation—perhaps "physics for poets" or "rocks for jocks." Such introductory courses focusing on specific disciplines cannot produce scientifically literate graduates. The students who take the geology offering will learn nothing about quarks or superconductors, while those who take physics will remain uninformed about the underlying causes of earthquakes. Neither physics nor geology classes touch on such vital modern fields as genetics or materials science. Perhaps more disturbing, few students—even science majors—ever learn how these arbitrary divisions of specialized knowledge fit into the overall sweep of science.

Science forms a web of knowledge about the universe, and the key to scientific literacy is general science education. To produce scientifically literate graduates, colleges must offer courses that encompass all the physical and life sciences, emphasizing general principles rather than esoteric detail. Many ways exist to achieve this kind of synthesis, but any general treatment should take advantage of the fact that virtually everything in science is based on a few simple ideas. If asked, every scientist would come up with a list that included Newton's laws, the atom, natural selection of species, and the genetic code.

We have found it particularly useful to organize scientific knowledge around a series of 19 overarching principles. The most basic principle, the starting point for all science (and any science course), is the idea that the universe is regular, predictable, and quantifiable. (It is remarkable how many college freshmen, even science majors, have no clear idea of how science differs from religion, philosophy, and art as a way of understanding our place in the cosmos.)



PHIL HOCKING, FOR THE CHRONICLE

Next come the principles shared by all the sciences; they include Newton's laws governing force and motion, the laws of thermodynamics governing energy and entropy, the equivalence of electricity and magnetism, and the atomic structure of matter. These are not abstract concepts. They apply to everyday life, explaining, for example, the reasons for seat belts, the physics of making a pot of soup, and the contrast between static cling and refrigerator magnets. In one form or another, all of these ideas appear in virtually every elementary science textbook, regardless of discipline.

Once the general principles have been laid down, we can look at specific natural systems such as galaxies, the stars, the earth, and living things. For each of these systems, additional principles have to be stated, which, together with the previous ones, bind all the subject matter together. For example, in astronomy we can show that stars and planets form and move in accordance with Newton's laws; that stars eventually die as dictated by the laws of thermodynamics; that nuclear reactions fuel stars by the conversion of mass into energy; and that stars produce light as a consequence of electromagnetism.

Two basic ideas—plate tectonics and earth cycles (rock, water, and atmosphere)—unify the earth sciences. The laws of thermodynamics decree that no feature on the earth's surface is permanent. This principle can be used to explain geologic time, gradualism, and the causes of earthquakes and volcanoes. The fact that matter is composed of atoms tells us that individual atoms in the earth system—for example in a grain of sand, a gold ring, or a student's most recent breath—have been cycling for billions of years.

Living things are arguably the most complex systems that scientists attempt to understand. But we believe that five basic principles apply to living systems: All are based on chemistry. All are made up of cells. All use the same genetic code. All evolve by natural selection. All are interconnected.

In developing and teaching a science course based on these unifying principles, we have found that we can bring science alive for students because any topic touching on science and society can be used to illustrate the general principles. Any specific event—an earthquake or volcano, a flood or drought, a comet or eclipse—involves the basic laws. Discoveries of new materials, reports of environmental dilemmas, or breakthroughs in medical research all can be used to amplify the core concepts. Similarly, any question from the class (and there are lots of them) can be answered in part by referring to a basic principle. For example, one student's question about cystic fibrosis in her family led to a more general discussion of genetic diseases and from there back to the genetic code.

ALTHOUGH THE NEED for courses based on this sort of unification of the sciences seems clear, we frequently hear the objection that no one will be able to teach them. Underlying that objection is the belief that only physicists can teach physics, only biologists biology, and so on. If that is so, then we must face the sobering possibility that most scientists are themselves scientifically illiterate outside their own narrow specialties.

Whether or not this is true, if colleges are to produce scientifically literate graduates, at least a few members of the science faculty at each college and university must be prepared to teach general science courses. University administrations always have been quick to reward science professors who do good research and produce a few talented Ph.D. graduates every year. Now, they must be just as quick to reward the generalist who produces a class of scientifically literate non-scientists every year.

Few scientists enter teaching with the broad knowledge necessary to present a general overview of science. But all science faculty members should have the ability to learn the basics of the other disciplines. Some colleges may tap senior scientists, who have the most breadth of experience, to present this material. Others may call on younger faculty members. In either case, if they were given a few incentives such as paid study time and weight in the promotion process, many science faculty members would embrace a chance to broaden their horizons. At George Mason University, for example, eight science professors—including tenured faculty members from physics, chemistry, geology, and biology—voluntarily attended a general science course we teach for a full semester to prepare to teach a core science course. They knew that their efforts were important for the educational program of the university, and their efforts were recognized and supported by the administration.

Science educators have created a system that alienates students from science from their earliest years. At each grade level, the accumulated vocabulary and data winnow out more students. By returning to general science courses for all students, colleges can in some measure reverse that trend. Our goal must be to produce college graduates who can see that scientific understanding is one of the crowning achievements of the human mind, that the physical universe is a place of magnificent order, and that science provides the most powerful means for discovering knowledge that can help us understand and shape our world.

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