Science Literacy: The Enemy Is Us

Are research scientists themselves to blame for many of the problems of undergraduate science education?

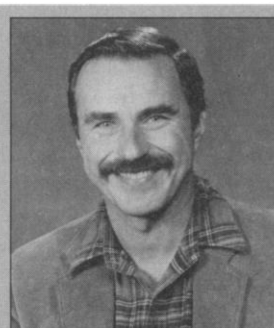
AT A SEMINAR ON SCIENTIFIC LITERACY LAST year, geophysicist Robert Hazen performed a little experiment on his peers. He asked 25 geophysicists at the meeting to explain the difference between DNA and RNA, two molecules that are central to understanding modern biology. "Of those 25 people, only two could give a cogent description of the difference," says Hazen, who is at the Carnegie Institution of Washington, and they specialized in fossilized organic molecules, a field that demands knowledge of DNA and RNA. On another occasion, Hazen says, he was speaking with a Nobel Prize-winning chemist about a recent earthquake when he discovered that the chemist had never heard of plate tectonics, the theory that underlies all of modern geology and geophysics.

These embarrassing episodes are not anomalies, but examples of a general state of affairs among scientists, say Hazen and physicist James Trefil, authors of a new book, *Science Matters: Achieving Science Literacy*. Conversations with colleagues around the country have convinced the co-authors that scientists often know little or nothing about fields of science outside their own. And the situation is more than an embarrassment, Hazen and Trefil say. They charge that this scientific illiteracy among scientists lies at the heart of the problems with undergraduate science education—a system that apparently produces large numbers of adults who believe in astrology, don't believe in evolution, and can't remember whether the earth goes around the sun or vice versa.

According to Hazen and Trefil, a vicious cycle is at work. Scientists with little knowledge of the broad sweep of science teach narrowly focused classes to undergraduates—and it's no surprise that most of the students are turned off, while those who do go on to become scientists end up as narrowly educated as their teachers. One remedy would be to teach a new kind of broad science course to undergraduates who are not majoring in science—Trefil and Hazen are offering such a course at George Mason University in Fairfax, Virginia—but there's a problem: Very few scientists have the breadth of knowledge or the interest to teach such courses.

Hazen and Trefil have attracted plenty of attention for their ideas. They have written essays for ***Newsweek***, ***The Chronicle of Higher Education***, and several other magazines, and just last week they described their views in ***The New York Times Magazine***. They have also appeared on television and radio talk shows, and are touring the country to promote their new book.

Not surprisingly, Hazen and Trefil's indictment of the scientific illiteracy of their colleagues has not gotten universal praise. *Science* spoke with a number of scientists and educators interested in science teaching and found wide agreement with part of the message offered by Hazen and Trefil—that research scientists are often scientifically illiterate, at least in the sense that they know too little science outside their areas of expertise. Leon Lederman, a Nobel laureate in physics and director of Fermilab, offers himself as an example: "I don't know nearly enough molecular biology for my own pleasure." But most also agree with National Academy of Sciences president Frank Press that Hazen and Trefil overstate their case. "Most scientists [at least] know the broad paradigms of science," Press says. And, he adds, every campus has at least a few scientists with a wide knowledge of science. For his part, Hazen admits that he and Trefil "overstate the case a bit for dramatic purposes," but he insists that researchers don't know enough science outside their own fields.



George Mason University

"You have to know a field pretty well before you can teach it."
—JAMES TREFIL

Even if this is true, however, most of the scientists who spoke with *Science* did not see it as a hindrance to good teaching. "The scientists who want to teach general courses have no problems learning the other subjects," says John Truxal, head of the department of technology and society at the State University of New York at Stony Brook.

Trefil disagrees. "You have to know a field pretty well before you can teach it," he says. He's learned that from experience: It took 2 years before he was comfortable teaching a class in science literacy at George Mason, he says, because he was unfamiliar with large areas of science, particularly biology.

And, Hazen adds, the question of how quickly a researcher can pick up a subject is really beside the point. Scientists can indeed learn things outside their fields if they want to, but "they don't do it because they don't want to." And they don't want to, he says, because they are not rewarded for it.

This is the crux of Hazen and Trefil's argument: University faculty get tenure and grants by performing research, not by excelling at undergraduate education, so they have little or no incentive to improve science teaching by broadening their scientific knowledge. "You don't enhance your reputation in your field by teaching general science," notes Jim Adams, chairman of the values, technology, science and society department at Stanford University. "The only incentive to do it is because you believe in it."

The result, Hazen and Trefil say, is that university science courses are generally geared toward the few students who will eventually become scientists and engineers, rather than to non-science majors, because researchers are better rewarded for educating new scientists than for creating scientifically literate laymen. Scientific illiteracy among scientists also plays a role here, Trefil says, because "if you don't know about something, you don't value it." So scientists are often uninterested in teaching subjects outside their disciplines. Consequently, non-science majors who want to learn about science often are left with a choice between watered-down science courses such as "physics for poets" and history of science or science-and-society courses.

Harold Shapiro, president of Princeton University, agrees this is a problem. Now, he says, students get a "relatively narrow set of choices [of science courses] that don't work. We need a broad range of new approaches."

What types of new approaches? At George Mason University, Hazen and Trefil offer "Great Ideas in Science," a "science appreciation course" in the tradition of the art or music appreciation courses taught at many schools (see also 13 April 1990 *Science*, p. 158). In a single semester, the students are given a broad overview of science that is arranged around 20 basic principles (see accompanying box). One goal of the course, Hazen says, is for students to be able to

Science's Top 20 Greatest Hits

Robert Hazen and James Trefil say that most scientists will basically agree on which are the most important and fundamental ideas underlying all of science, but will they? Here is the two authors' list of the 20 "great ideas" of science. Compare them with your own Top 20.

The list begins with the broad worldview shared by all scientists that makes the scientific method practical:

▶ 1) **The universe is regular and predictable.**

Then Hazen and Trefil list six overarching principles that underlie all the rest of science, beginning with Newton's three laws of motion, which are summarized by:

▶ 2) **One set of laws describes all motion.**

The First and Second Laws of Thermodynamics govern the behavior of heat and energy:

▶ 3) **Energy is conserved;** and

▶ 4) **Energy always goes from more useful to less useful forms.**

Everything we know about electricity, magnetism, and electromagnetic radiation, which includes visible light, infrared and ultraviolet radiation, microwaves, x-rays, and radiowaves, starts with the realization that:

▶ 5) **Electricity and magnetism are two aspects of the same force.**

The fundamental nature of matter and energy is summed up by two more great ideas:

▶ 6) **Everything is made of atoms;** and

▶ 7) **Everything—particles, energy, the rate of electron spin—comes in discrete units, and you can't measure anything without changing it.**

Next, Hazen and Trefil survey the different basic fields of science, identifying the fundamental ideas underlying each, starting with chemistry:

▶ 8) **Atoms are bound together by electron "glue";** and

▶ 9) **The way a material behaves depends on how its atoms are arranged.**

In physics, the authors find five great ideas, whose subjects range from fundamental particles to astrophysics and cosmology:

▶ 10) **Nuclear energy comes from the conversion of mass;**

▶ 11) **Everything is really made of quarks and leptons;**

▶ 12) **Stars live and die like everything else;**

▶ 13) **The universe was born at a specific time in the past, and it has been expanding ever since;** and

▶ 14) **Every observer sees the same laws of nature,** which is a summation of Einstein's special and general theories of relativity.

Modern geology, geophysics, and earth sciences rest on the understandings that:

▶ 15) **The surface of the earth is constantly changing, and no feature on the earth is permanent;** and

▶ 16) **Everything on the earth operates in cycles.**

And to comprehend biology, the study of life on earth, one needs to know that:

▶ 17) **All living things are made from cells, the chemical factories of life;**

▶ 18) **All life is based on the same genetic code;**

▶ 19) **All forms of life evolved by natural selection;** and

▶ 20) **All life is connected,** which is a statement about ecology.

Have Hazen and Trefil left anything out? Have they put anything in that shouldn't be there? For this survey only, fax us your comments at 202-842-0317 by 8 February, and in a future issue *Science* will print a selection of readers' suggestions concerning what students should know to be scientifically literate. ■ **R.P.**

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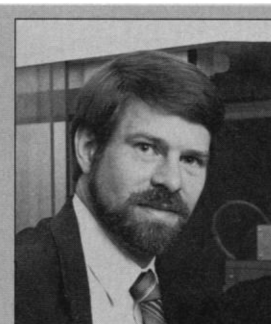
understand newspaper articles on global warming, the Superconducting Super Collider, gene therapy, or other current scientific issues.

Press is even more ambitious, proposing that, as part of a core curriculum, every non-science major should have a 2-year general science and technology course. Others, such as Truxal, suggest using topics of general interest to students, such as global warming or the ethical implications of new developments in medicine, as a way of introducing students to the scientific method. "What you really try to do is improve the students' self-confidence so that they can pick up material and learn it on their own," Truxal says.

Whatever form the new courses take, however, a number of problems face teachers who push for putting them into college and university curricula, Press says. There are few textbooks for general science education courses, for instance, and the division of science faculties into traditional departments makes the question of who teaches general science courses a tricky one. "Every department wants the enrollment and teaching credits," Press says. Further, researchers often have a conservative attitude toward how science is taught. Press adds, "The president of one of the country's most prestigious universities told me, 'My science faculty is my worst enemy when I raise that issue [of teaching general science courses].'"

"Universities should reward faculty members for excellence in science teaching."
—Robert Hazen



Carnegie Institution of Washington

Hazen and Trefil would like universities to endow chairs for undergraduate science education or at least award tenure to a handful of faculty members based on their teaching instead of their research, but few of the scientists interviewed by *Science* think this is a good idea. "Is the education of undergraduates more satisfactory at institutions that don't have a commitment to research?" Shapiro asks. "I think it is not." Lederman adds, "You shouldn't have to bribe people to be teachers." The traditional strength of the universities has been to have teachers who are also active researchers, he notes, and the solution is to keep this system but to focus on "improving the ethic of teaching" among researchers.

Despite the apparent difficulties in revamping the approach to teaching science to undergraduates, Press thinks there is enough interest in the subject now that it should be possible to effect major changes nationwide. "The way to get going is this: There are a few universities that are models for the rest of the country. If four or five of the role models would institute such programs of general science education, everybody would follow." And that might improve science literacy both among scientists themselves and the general population. So, Press says: "Get going, you have an obligation to improve science education." ■ **Robert Pool**