JAMES TREFIL

Science Education for Everyone

Why and What?

The most important use our students will make of whatever science they acquire will be in their future role as citizens

THE NOTION THAT a liberally educated person should know some science is well accepted these days. You would have to go pretty far in American academe to find the kind of academics C. P. Snow talked about a half century ago in *The Two Cultures*—the ones who were proud of their ignorance of the second law of thermodynamics. What I would like to explore in this essay is not so much the "whether" of general science education, but the "why." What exactly constitutes good science education, and how can we recognize when our students have received it? Once we have answered this question, the answer to the "what" question—the actual content of the curriculum—is relatively easy to find.

Before going on, I need to make one point. There are (at least) two different kinds of things that go under the name of "science education." One involves the education of future scientists and engineers—an endeavor that is, I think, in pretty good shape (although improvements are always possible). The other involves the education of what I call "the other 98 percent"—the students who will not go on to careers in science and technology. It is this latter sort of education that I want to discuss. In particular, I want to ask what sort of education the other 98 percent should get in the sciences.

There is a long history of thought on this subject in both the United States and England. John Dewey set the stage for our current debate in 1910, when he argued that the proper goal of science education (what we would call today general education in science) was to create a "scientific habit of mind." Dewey was somewhat vague on the details of this goal, although his

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main motivation seemed to be social utility (what I will call the "Argument from Civics" below). By the 1930s, however, University of Wisconsin educator I. C. Davis had expanded Dewey's notion as follows:

> We can say that an individual who has a scientific attitude will (1) show a willingness to change his opinion on the basis of new evidence; (2) will search for the whole truth without prejudice; (3) will have a concept of cause and effect relationships; (4) will make a habit of basing judgment on fact; and (5) will have the ability to distinguish between fact and theory. (Davis 1935, 117)

Who can argue with that?

The problem with this sort of goal—a goal that, I suspect, the great majority of academic scientists would endorse—is that it is both completely unrealistic and totally out of line with the way science is evolving. If we have this sort of goal in mind, we will treat the purpose of general science education as being the production of students who are, in effect, miniature scientists. "If we can't make you into a full-fledged scientist," the argument seems to go, "we'll get you as far along that track as we can." In the words of Nobel Laureate Carl Weiman of the University of British Columbia, scientists engage in the general education of students because "we want them to think like us."

The result of this attitude is the almost universal general education science requirement of "eight hours of science," with or without a laboratory, that we find in American academe. Departmentally based, these courses typically are of the "Physics (or Chemistry or Astronomy or Biology) for Poets" type, aiming to get the students through a simplified version of the main concepts of a single discipline. The problem, of course, is that anyone who has spent time in the trenches knows that very few students are going to acquire a "scientific habit of mind" in these courses, and the majority of them can be counted on to forget most of what they learned shortly after the final.

The Argument from Civics

My sense is that the main problem with general education in the sciences is that we have set ourselves the wrong goal. Rather than think about the problem of producing miniature scientists, let me advance a Modest Proposal for an alternate goal: *Students should be able to read the newspaper on the day they graduate*. What I am suggesting is that we think about the way our students will use their science education in later life, and then adopt goals that support those uses.

As my Modest Proposal suggests, I think that the most important use our students will make of whatever science they acquire will be in their future role as citizens. Pick up a newspaper or listen to a news broadcast any day and you will find issues that relate to science—global warming, stem cells, food additives, genetic engineering, and new advances in medicine, to name just a few examples. These sorts of issues form part of the public discourse that is the fabric of our democracy, and one of the most important goals of education is to prepare students to be active participants in it. The idea that the primary goal of general science education is to prepare students to assume the role of active citizens is what I call the "Argument from Civics."

It is important to realize that the kinds of issues that arise in public debate rarely involve scientific questions alone. Instead, the science acts as a kind of entrance ticket into the debate—a necessary background that allows a person to get to the real issues involved. Take the ongoing stem cell debate as an example. A person who has no concept of the molecular machinery of life is going to have a hard time understanding what a stem cell is and why it is important. An elementary understanding of some basic modern biology, however, allows that person to enter the real debate, which, until recently, was inextricably bound up with the moral and religious issue of whether the sacrifice of a week-old embryo to harvest stem cells was ethically justifiable. This is not a scientific question at all, but the point is that you cannot bring your personal moral calculus to bear on the issue until you know enough science to understand what a stem cell is.

As of this writing, it looks as if this particular issue may be resolved by a scientific advance (basically, the newfound ability to manipulate DNA to turn mature skin cells into functioning stem cells). I would like our students to understand the collective sigh of relief that went up in the scientific and religious communities when this result was announced in the fall of 2007.

When we take as our goal the production of students who are comfortable handling science-related issues that arise in public

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debate, two propositions follow immediately, both of which are profoundly out of tune with the current academic consensus: (1) the students need to know something about all areas of science, rather than a lot about a single area; and (2) the students do not need to be able to "do" science.

Take the current debate over global warming as an example of this first proposition. It involves the burning of fossil fuels (chemistry), the effect of carbon dioxide on the earth's energy balance (physics), the changes this may produce in the climate (earth sciences), and the effects that those changes may or may not have on the biosphere (biology). All of this has to be understood before we can get to the real issues in the debate, which involve questions about the level of obligation we have to future generations, the level of stewardship we should show toward the planet, and so on. Or take another subject like the debate over the long-term storage of nuclear wastes. This involves things like the understanding of radioactivity (physics), the question of the long-term stability of the Yucca Mountain facility (geology and hydrology), and the possible consequences of the release of radioactive materials (biology).

As these examples show, if we are to equip our students to function as citizens in the increasingly complex world we are building, we will have to teach them something of all the sciences, and not have them specialize in a single discipline. I would argue that a student who takes a Physics for Poets course, and who leaves the university without hearing the term "DNA" uttered in a classroom, has been poorly prepared to carry out his or her role in American democracy. (I would say the same about a student who satisfied his or her science requirement by taking a biology course, and who never heard the term "alternate energy" in a classroom.) It seems self-evident that if we expect our students to be able to deal with the kind of complex interdisciplinary problems that arise in public debate, the very least we can do is teach them the basic principles that underlie these problems.

A common response to the notion of teaching all of the sciences is the claim that the standard type of courses really teach something called the "scientific method," and that this will magically give students the background they need to read the newspaper on the day they graduate. This argument is so silly that I scarcely know where to start commenting on it. If it were applied to any other field, its vacuity would be obvious; after all, no one argues that someone who wants to learn Chinese should study French, acquire the "language method," and learn Chinese on his or her own. If we expect our students to understand the basic principles of ecology or geology, we should

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teach those principles explicitly. To do otherwise is to indulge in what I call the "teach them relativity and they'll work out molecular biology on the way home" school of thought.

Incidentally, the notion that there is a magical "scientific method" explains a bizarre feature of the modern scientific community. I am referring to the fact that, outside of their fields of specialty, professional scientists, as a group, are probably the most scientifically illiterate group in the United States. The reason is simple: scientists are never required to study science outside of their own fields. The last time a working physicist saw a biology textbook, for example, was probably in high school. If you do not believe me, ask one of your scientific colleagues how he or she deals with public issues outside of his or her field. Chances are you'll get an answer like "I call a friend," a technique I refer to as having recourse to the Golden Rolodex.

Thus, the kind of education offered in the modern, departmentally based university is not really designed to give our students—even science students—the sort of background they will need to function as citizens. The same can be said for the notion that the purpose of general education is to produce students who can do science at some level. I would argue that these sorts of skills are largely irrelevant to the goal of citizenship. The best argument I can think of to support this proposition comes from my own background, where courses with titles like "Music Appreciation" and "Survey of Renaissance Art" played a major role in my education. They taught me something about how to get more out of an opera or a visit to a museum, but nothing at all about how to play a musical instrument or produce a painting. When I really want to annoy my colleagues, I like to say that demanding that our students do real science is equivalent to stationing guards at an auditorium entrance and allowing no one to enter unless he or she can play the violin.

The way science is done today

As I suggested above, the traditional view of general education is out of touch not only with the need to produce scientifically literate citizens, but also with the way science itself is developing. Over the last thirty years, a revolution has occurred in the way research scientists carry out their jobs—a revolution whose consequences have not even been considered by those concerned with general education. I am talking about the impact on science of the availability of massive computational and data storage capability.

Throughout most of history, the ultimate limitation on the level of complexity with which we could describe the universe was the capability of the human brain. Isaac Newton, for example, was able to describe the motion of a single planet around the sun by solving equations with pencil and paper. His followers struggled (unsuccessfully) for centuries to describe a system of several planets circling a star—and never mind the thousands of moons, asteroids, comets, and other stuff that is actually out there. The point is this: the real world is extremely complex, but our ability to describe that complexity has always been limited.

Until recently, that is. The human mind has produced a tool—the digital computer—that is much better than the human brain at dealing with certain kinds of complexity. Each of us can remember only so much, for example, but somewhere there is a computer (or system of computers) that can tell you every passenger flying on United Airlines tomorrow. A computer can perform in seconds a task that would take a human being hours (think of calculating your income tax, for example). What this means is that today, for the first time, we can access and store huge amounts of information about physical systems, and then manipulate that information in massive computer codes capable of producing predictions for the behavior of systems of unprecedented complexity. And, of course, as science comes to be dominated by these sorts of computer outputs, the kinds of questions that the ordinary citizen has to deal with will change.

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Take the current discussion about global warming as an example. The basis for all of the predictions about the future of our planet are computer codes that go by the name of General Circulation Models (GCM). In a GCM the atmosphere and ocean are broken up into millions of boxes, and in each box the known laws of physics and chemistry are applied to predict future behavior. The computer then adds up the results of all of these calculations and makes its prediction about the climate.

To make such a model work, you have to put in thousands of different pieces of data and describe thousands of different processes. For example, ice reflects sunlight while water absorbs it, so the model has to deal with the formation of sea ice—a complex process. Clouds, vegetation, and land use changes all have to be taken into account, as do many other effects, and the final results of the calculation depend on the accuracy of your input data and the validity of your description of the individual processes (such as the formation of clouds), as well as the validity of your description of the interaction among all the processes. This is a calculation of enormous complexity, and I suspect that there is not a single individual in the world who really understands the working of the entire GCM code.

Yet every citizen is going to have to make decisions about public policy and private lifestyle choices based on his or her assessment of the validity of those computer outputs. A moment's reflection will convince you that this assessment is actually composed of a layered set of questions, each more general than the last. The question at the bottom concerns the individual inputs into the computer model—for example, did we get the sea ice changes right? This is a purely scientific question, one probably best left to the experts. The next question involves what happens when these inputs are put into a GCM. Will the final results be sensitive to whatever uncertainties there are at the first level? At the next level, we face the problem of validation—do the descriptions of the world in the computer match the world we actually live in? This is a question that will be debated publicly by scientists, and one that the average citizen can follow. It is only after we get through all of this that we can get to the true bottom line: what are we going to do (or not do) about global warming? No matter how complex the science behind future debates, the outstanding questions will always be layered in this way.

What background knowledge does the average citizen need to deal with these layered questions for himself or herself? I think it is clear that the standard lab-based science course is not going to get the student very far along toward this goal. Watching an ice cube melt or dissecting a (real or virtual) frog provides very little understanding of the complexities of modern computer-driven science. It is just too far from that ice cube to the output of a GCM.

There is, however, one educational scheme that I believe forms a necessary prerequisite to tackling issues like global warming. I call it the "Great Ideas" approach to teaching science. It relies on the fact that science is basically hierarchical in nature, with a relatively small number of general principles (conservation of energy, for example) forming the basis for our understanding of a wide range of phenomenon. These Great Ideas form the skeleton, the framework, of our understanding of the universe, and they span all fields of science. I would suggest that an understanding of these ideas and their interactions is what every student needs to know in order to begin acquiring the ability to deal with the issues he or she will encounter as a citizen in the twenty-first century.

The reader may or may not agree with this approach to general education in the sciences, but I think we can all agree that we need to start bringing the system more into line with the way science is done today and the way our students will encounter it in their lives. Time to get to work! □

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REFERENCE

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