Cell

A Wakeup Call for Science Faculty

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By changing the way we teach the introductory science courses in our colleges and universities, we can attract many more talented students to science careers. At the same time, we will be fostering positive public attitudes about science that are critical for a successful modern society.

Rethinking Undergraduate Science Courses

Most scientists are passionate believers in science as a critical discipline for improving the human condition (Bronowski, 1956; Glass, 1970; Alberts, 2005). We therefore care about ensuring the future of science by recruiting our most talented young people into science careers. But too few of us have recognized that we can cast a much wider net for the best talent if we change the way we teach science to undergraduate students in our colleges and universities.

Different people have different sets of skills. A maximally productive system of education should provide all students with the opportunity to discover both what their particular abilities are and what types of work they might enjoy as adults. These two types of discoveries are closely related. Human beings derive a great deal of pleasure from a feeling of competence (White, 1959), and students are likely to prosper in careers that match their particular skill sets.

Tragically, the present system of education in the United States rarely gives young people a chance to test their potential abilities as future scientists. In particular, very few students are exposed to science curricula that allow them to explore the world in the way that working scientists do. Instead, science education in the US—from elementary school through college—usually focuses on helping students absorb what scientists have already discovered about the world.

One might expect students to be exposed to the real world of science through the laboratory classes that are associated with many science courses. Unfortunately, these laboratory classes generally resemble cookery lessons, and they are remembered even by scientists as unpleasant and dull. Even today, my personal experience is not atypical. After several years as an undergraduate science major at Harvard University, I estimate that I had spent more than 3000 afternoon hours in laboratory science classes. Fascinated by the physical chemistry lectures but unable to face a second semester of its laboratory requirement, I somehow found the courage to petition for relief. To my surprise, I was allowed to replace the offending laboratory work with the same amount of time spent in a research laboratory with my official Harvard tutor (Jacques Fresco, later a professor at Princeton University). Only then did I have the chance to discover what science really is and to recognize my aptitude for it.

I strongly suspect that many of my most talented and creative colleagues were less patient than I, and that they were among the 50 percent of students entering Harvard University who routinely switch out of an intended science major at some point in their first two undergraduate years (Seymour and Hewitt, 1997). One can only wonder how many great future scientists have been lost in this way.

In my opinion, the primary aim of any undergraduate introductory science course—whether in biology, chemistry, physics, or earth sciences—should be to enable students to appreciate and participate in science as a special way of knowing about the world (Moore, 1993). Our goal as teachers and educators should be to expose our students to the discovery process and to excite them about challenges at the frontiers of knowledge. We should try to make students understand why it is crucial that any scientific result be confirmed by other scientists, and why a scientist can never be sure that he or she has the final answer about anything.

None of this will be possible unless we stop our current, counterproductive attempts to teach broad survey college courses—courses that aim to fill the heads of students with the most important facts that our own particular discipline has discovered about the natural world, without conveying to them how we came to know and understand these facts. In such courses, whether Biology 101 or Chemistry 101, there is simply no time to pursue any one aspect of the field in enough depth to make the science come alive. As scientists, we complain when our children and grandchildren confront similar shallow, almost meaningless survey science courses in middle and high school. But we generally fail to recognize that these courses are modeled on the introductory science courses at prestigious colleges and universities that, as science faculty, we continue to tolerate and teach (National Research Council, 2002).

An analogy from a completely different field may help to clarify my point. As a high school student, I had taken several history courses, and I had managed to memorize enough facts and dates to do well on all of the exams. But it was only in my second year of college that I finally came to understand the importance and the nature of this discipline. The course was "Soc

Sci 2," a history of Western civilization taught by Harvard professor Sam Beer. The standard college course, like the standard high-school course, consisted of a year-long survey of ancient, medieval, and modern times and was supported by a bulky textbook and 70 lectures. Professor Beer, however, decided to teach six periods of history (from the Magna Carta to the Russian Revolution), each lasting for about half a century, over the course of six months. This allowed us to read some contemporary sources, as well as scholarly analytical essays written by historians. Unlike high school, there was no textbook assigned to be memorized. This history course profoundly shaped my view of the world. Why can't we use this same type of approach for teaching the college courses that introduce each scientific field?

A Helping Hand for School Science Teachers

In response to a request from the Governors of all 50 US states, the National Academies produced the first-ever National Science Education Standards for the United States a decade ago (National Research Council, 1996). Designed for students 5 to 18 years old, these standards propose that science should become a core subject that is taught along with reading, writing, and mathematics in every school year, starting in kindergarten. Emphasis is placed on teaching science as inquiry, rather than on teaching science as the memorization of facts and terms (National Research Council, 2000). This type of science education involves active learning, and it takes advantage of children's curiosity by increasing their understanding of the world through problem solving. Thus, for example, instead of having 5th graders memorize the relationship between the period of a pendulum and its length, students work in small cooperative groups with weights, string, tape, and a pencil (as fulcrum). They are coached by the teacher to discover for themselves which of the numerous possible variables affect the swing rate of a pendulum. And once the class comes to the realization that only a single variable is relevant, they are challenged to construct a pendulum with a specified swing rate without testing it first.

Hands-on inquiry learning can also serve as a core that can be used to render lessons in mathematics, writing and reading more meaningful. Through such science classes, school can become exciting even for the least motivated students. The lesson on pendulums, for example, leads naturally to the graphing of results and an understanding of dependency relationships. And clear writing is fostered when students are required to communicate concisely what was done in the pendulum experiment, and what the results mean. In fact, research on the effects of hands-on science learning for children has demonstrated substantial gains in literacy, as well as in the understanding of science (Amaral et al., 2002). However, parents need to be convinced that this type of learning makes sense for their children and to understand its nature and its value. It is for this reason that the National Academies published a booklet for parents entitled *Every Child a Scientist*, which like all other Academies publications is freely available on the Web (National Research Council, 1998).

Unfortunately, if we continue to emphasize all of the facts of science in our college introductory courses, parents and politicians will continue to expect high-school science courses based on textbooks that convey a string of scientific facts and nothing more. The high-school science course in turn will inevitably continue to serve as the model for the middle-school science course and so on. Retargeting our college introductory science courses will therefore greatly benefit the teaching of science at lower levels by changing everyone's view of what science education is all about. In addition, we cannot expect school teachers to be able to teach science as a form of inquiry if they have never experienced scientific inquiry themselves during their college years. All school districts should provide continuing professional development for their science teachers, but experience with science as an active process in college science classes is also critical.

A Wakeup Call for Scientists

If I had only a vague understanding of how science works after 2.5 years as a science major at Harvard University, how can we expect most US citizens, who have had far less exposure to the ideas of science, to understand this critical enterprise? And if they fail to comprehend the nature of science, how can we expect them to respect its predictions about the future, to understand its limits (for example, in investigating the supernatural), or to deal with its discoveries that will profoundly shape their lives? As the world becomes ever more crowded, interconnected, and complex, will our societies continue to rely on scientific explanations for causality? Or might there be a return to superstition and witchcraft as a more attractive way of thinking about the world?

Because the pace of scientific discovery continues to accelerate, the scientific and technological advances in this century will almost certainly exceed those of the past 100 years. The spread of science—and of scientific judgments about the effects of current actions on the future —to every nation is urgently needed to create a more prosperous and rational world. But already there are clear signs that our societies are ill-prepared for what science brings. Witness, for example, the overwhelmingly negative reaction in Europe to genetically engineered improvements to agricultural crops—a sentiment that threatens to block the use of this technology to help poor farmers in Africa. And in the United States, many people are susceptible to dogmatic talk-radio hosts who promulgate simplistic solutions to complex problems. There is also a growing backlash against vaccination, and we currently face challenges to the teaching of evolution in 40 of the 50 states of one of the world's most developed nations.

More than 50 years ago, Prime Minister Nehru emphasized the importance of what he called a "scientific temper" for India. By this I presume that he meant a society that exhibits the creativity, openness, and tolerance that are inherent to science—a requirement for his diverse nation. In today's highly interactive global society faced with the inevitable spread of advanced technologies that can be misused, our long-term survival depends on creating a scientific temper for the world.

Old habits die hard, and I have been disappointed to discover that this is especially true in academia. What will it take to grab the attention of science faculty at US colleges and universities and make them understand the urgent need for new ways to teach science? We have recently received a wakeup call. A new survey finds that two-thirds of Americans agree with some of our political leaders that "intelligent design theory" should be taught as an alternative *scientific* explanation of biological evolution. What does this mean? According to intelligent design theory, supernatural forces acting over time have intervened to shape the macromolecules in cells, thereby forming them into the elegant protein machines that drive a cell's biochemistry (Alberts, 1998). In other words, at least from time to time, living things fail to obey the normal laws of physics and chemistry.

Teaching intelligent design theory in science class would demand nothing less than a complete change in the definition of science. This definition would give those of us who are scientists an "easy out" for the difficult problems we are trying to solve in our research. For example, why spend a lifetime, constrained by the laws of physics and chemistry, trying to obtain a deep understanding of how cells accumulate mutations and become cancerous if one can postulate a supernatural step for part of the process? Yet we can be certain that, without the deep understanding that will eventually come from insisting on natural explanations, many powerful cancer therapies will be missed.

The idea that intelligent design theory could be part of science is preposterous. It is of course only by insisting on finding *natural* causes for everything observed in nature that science has been able to make such striking advances over the past 500 years. There is absolutely no reason to think that we should give up this fundamental principle of science now. Two-thirds of Americans might seem to have no real idea of what science is, nor why it has been so uniquely successful in unraveling the truth about the natural world. As I write, the Kansas State Board of Education has just changed the definition of science in revisions to the Kansas State Science Standards to one that does not include "natural explanations" for natural phenomena. What more proof do we need for the massive failure of our past teaching of biology, physics, chemistry, and earth sciences at high schools, colleges, and universities throughout the United States?

For all those who teach college biology, the current challenge posed by the intelligent design movement presents an ideal "teachable moment." I believe that intelligent design *should* be taught in college science classes but not as the alternative to Darwinism that its advocates demand. It is through the careful analysis of why intelligent design is *not* science that students can perhaps best come to appreciate the nature of science itself.

I conclude that it is way past time for us to completely redesign our undergraduate introductory science courses, so that all students come into direct contact with science as inquiry and are forced to develop their own understanding of what science is, and what it is not (National Research Council, 1999; Handelsman et al., 2004; DeHaan, 2005). We must recognize that it is not only the potential future scientist who needs to experience and understand science in his or her first years of college—every college student must be given this opportunity.

As scientists, the ball is now clearly in our court: spreading a scientific temper throughout the world is up to us.

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