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Science and Society

For years, tests and surveys have highlighted a paradox in American science education: the nation that leads the world in research brings up the rear in public understanding of science. How can this be? The Third International Mathematics and Science Study, begun in 1995, yielded an important insight. Comparing the educational systems of 50 countries, the study found that US students scored near the top of the group at the fourth-grade level. Unfortunately, it's all downhill after that. By the eighth grade, the American students drop into the average group, and they almost reach the global bottom by the time they finish high school. The US research enterprise compensates for this nosedive by focusing on undergraduate and graduate student training. This approach explains the paradox in which an ample pool of highly qualified scientists drives competitive research while the general public remains largely ignorant. Still, the kindergarten-through-12th grade (K–12) educational decline has far-reaching implications for research, none of which are positive. As Costello Brown, Director of Educational System Reform at the National Science Foundation (NSF; Arlington, Virginia, USA) puts it, "We are not even going to have the people who can vote responsibly as Americans on issues surrounding global warming, the environment, and whatever else if they don't know the difference between a pound and a millimeter." Education experts like […]

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Education experts like Brown often speak in the future tense, but current policy debates on issues like stem-cell research, cloning, and the teaching of evolution (see "In the beginning, there was darkness") show the legacy of this ongoing problem. Now professional organizations and some individual researchers are coming to appreciate the volatility of a system in which a benighted public underwrites groundbreaking science. The problem can no longer be ignored, and the scientific community needs to become part of the solution.

A colonial organism

Science education in the US represents the melding of two of the most complex systems ever devised by humans: the body of scientific knowledge and the institution of American public education. There is general agreement that this Byzantine enterprise is in need of major reform, but the factors that drove its deterioration are difficult to pinpoint.

Following a longstanding national tradition, fingers of blame have been pointed in virtually every direction. Even a cursory study reveals a plethora of possible causes. A post-Sputnik wave of science teachers, drawn by patriotism and relatively high salaries, has mostly retired. Many school districts are going broke. More students now come from unstable households, many below the poverty line. Celebrities and political leaders increasingly embrace pseudoscientific or antiscientific beliefs. With the advancement of knowledge, science itself has become more complex.

While many of these trends are not unique to the US, efforts at reforming science education here face the added obstacle of federalism. More than almost any other area of public policy, education in the US is controlled at the state level, so current reform strategies call for changing 50 autonomous systems. "I would say that if we were going to have a big reform of K–12 science education in this country, it would have to come from the federal level," says Beth Montelone, a biologist at Kansas State University (Manhattan, Kansas, USA), who is involved in school reform.

State control of education, however, is a sacred cow in US politics. Asked if federal control would make curriculum changes easier, the NSF's Brown responds with a chuckle, "That's a question that is hypothetical. As a federal bureaucrat, I'm not even going to go down that road." Brown explains that the NSF and other federal agencies have to help shape states' agendas indirectly: "We don't

Reform from the local to the global. High-school students in the US use inexpensive photometers to confirm NASA data on atmospheric aerosol levels — and help to demonstrate the effectiveness of taking science education beyond the classroom.

➲ **In the beginning, there was darkness . . .** In March, the Ohio State Board of Education held a hearing to listen to arguments about evolution. Rather than refuting the classic creationist doctrine that the earth was created in six days, scientists testifying before the board had to answer a more subtle version of creationism called "Intelligent Design" by its proponents. Intelligent Design advocates argue that living organisms are so complex that they could not have arisen through Darwinian evolution — instead, the complexity hints at an "intelligent designer" driving the process.

Lawrence Krauss, a physics professor at Case Western Reserve University, prefers to call Intelligent Design what it is: "an attack on science." Krauss, author of *The Physics of Star Trek* and other popular books, adds that "we do a miserable job of conveying to people what science is already, and this is just going to make it worse."

Unfortunately, the situation in Ohio is not an aberration. In 1999, for example, the Kansas school board decided to discourage the teaching of evolution. Although this highly publicized decision was subsequently reversed, it is part of a nationwide pattern. Alabama's Board of Education now inserts a disclaimer undermining evolution in its biology textbooks, and the Illinois school board has gradually purged the word "evolution" from its curriculum, replacing it with "change over time." In Louisiana, one recent survey showed that 29% of the state's biology teachers support teaching creationism.

State school boards are loathe to offend a politically powerful group, and the overall state of science education in the US leaves average citizens ill-equipped to take a stand on the issue. The result is that creationism, a peculiar doctrine supported by a minority of citizens, has permeated K–12 biology education nationwide.

Most scientists have taken a dangerously laissez-faire attitude about the issue, according to Krauss. "The scientific community has always just assumed that the correct idea will win out because that's the way it works in science," but "that approach doesn't work very well when there are people with a vested interest in the opposite happening."

say to them that you must do this particular curriculum or you must do that, but we say whatever you're doing has to have a logic and has to get more kids involved in science and math." The agency, which currently has a budget of more than $350 million dedicated to improving science education, can also assist grass-roots reform efforts once they have begun at the state or local level.

Whatever political difficulties confront science education, the key to the solution — and part of the problem — clearly lies with science teachers themselves.

Recruiting and retaining good science teachers, though, is difficult. "The teaching salaries for science and math majors are not competitive with jobs in the private sector," explains Jo Ellen Roseman, Acting Director of Project 2061, an educational reform effort at the American Association for the Advancement of Science (AAAS; Washington, DC, USA). Roseman adds that one obvious solution, offering higher salaries for math and science teachers than for other those in other areas, is "probably not something the unions would encourage."

Still, data collected by Project 2061 suggest that in affluent school districts, at least, a majority of high school science teachers have a degree in a scientific discipline. As is usually the case, poor districts do not fare as well. Other statistics from the project are less encouraging, including the finding that around half of all starting teachers will leave the profession within five years. "Some of our best teachers, I think, leave because their hands are tied for a variety of reasons. There are a lot of regulations that teachers need to meet, and those regulations may have little to do with what their students are actually learning," says Roseman.

Ironically, well-intentioned efforts to reform the system have often added to the stresses driving teachers away. Fads in educational theory have led school systems to adopt and then reject everything from "open-space" schools to "whole-language" reading, leading many teachers to regard proponents of change with a wary eye.

Recruiting problems and high turnover have predictable effects. "I think a lot of students get the message early on that the teachers are uncomfortable with [science], and therefore they're uncomfortable with it," says Lawrence Krauss, chair of the Department of Physics at Case Western Reserve University (Cleveland, Ohio, USA) and an outspoken advocate of educational reform. Krauss adds that role models outside the classroom amplify the problem, since "people who sort of outright proclaim their scientific illiteracy are valued greatly — like the current President of the US."

Waiting for the impact

Scientifically illiterate or not, the President, along with Congress, decided in 2001 to overhaul the Elementary and Secondary Education Act, the 1965 law that has defined the federal government's role in education. The huge phalanx of changes, titled the No Child Left Behind Act, maintains and even increases state-level control of education, but requires all states to implement a variety of measures aimed at increasing accountability, primarily through testing (see "Multiple choices"). The Act became law at the beginning of 2002.

No Child Left Behind is probably the most ambitious federal education reform in decades, but education experts understand that substantive change will necessarily be gradual. "We're dealing with difficult and complex issues . . . that don't really lend themselves to short-term fixes. One of the things that I think we've learned is that it requires sustained efforts to bring about sustainable change," says the NSF's Brown.

He should know. Brown directs the NSF's Systemic Initiatives, projects intended to help school systems make large-scale changes in science education. The initiatives have focused on two types of systems: rural districts with endemic poverty and urban districts with a range of problems. The results have been mixed. "There are some pockets of excellence where individual schools or clusters of schools have done a tremendous job with math and science. But the issues of scale in getting . . . a Chicago or a Detroit or an Atlanta to do it on a sustained level district-wide is still a major challenge. We haven't succeeded, but we've made an awful lot of progress."

But as a result of No Child Left Behind, the Systemic Initiatives are being left behind. The NSF has moved $160 million from the Systemic Initia-

tives budget into programs to help districts cope with the testing required by the new law. While currently funded Systemic projects will continue for the length of their grants, the program is not accepting new applications, and Brown expects it to be phased out.

While the government shifts its focus from one effort to another, the scientific community has been building a conceptual framework that has been conspicuously absent from US education: a national science curriculum. In 1993, The AAAS's Project 2061 released its *Benchmarks for Science Literacy*, describing the scientific knowledge students should have at different levels of schooling. The National Academy of Sciences (NAS; Washington, DC, USA) followed suit in 1996, advocating similar goals in its *National Science Education Standards (NSES)*.

Neither the *NSES* nor the *Benchmarks* carries any legal weight, but the credibility of the AAAS and NAS persuaded many states to align their science curricula with one or both documents. The result is a somewhat more uniform system, but still a patchwork. "I don't think any state has really wholeheartedly adopted the national standards without changing it somehow to fit that state," says David Vannier, Professional Development Coordinator for the Office of Science Education at the NIH.

Even with spotty implementation, though, the curricula provide a starting point for additional reforms. Currently, most US high schools teach biology first, then chemistry, and reserve physics for the most gifted students in their final year. Some researchers now advocate reversing this order, since understanding modern biology requires some understanding of chemistry, which in turn requires some understanding of physics.

Roseman agrees that "there are certainly some aspects or some key ideas to be learned in physics that need to be learned before some other ideas in chemistry or biology," but favors a holistic approach. In Project 2061's *Atlas of Science Literacy*, published in 2000, related concepts in the curriculum are linked together without setting rigorous divisions between physics, chemistry, and biology. Many European schools employ a single science course that links concepts like this, but Roseman concedes that "problems to implementation [in the US] are huge."

➲ Multiple choices. Nobody knows whether US schools will have more success teaching science in the future, but they will definitely have more tests. As a result of the No Child Left Behind Act of 2001, every state must implement an array of tests for students at various levels, as well as for teachers. The exams for different subjects are to be phased in over the next few years; student science tests will start in 2007.

Since there is no legally mandated national science curriculum, each state's test will be geared to its own standards and lesson plans — or, as many critics argue, vice-versa.

There is also concern that testing could amplify current inequities in the nation's educational system. "States that have more money can do more innovative testing [for] deeper concepts, but states that don't are going to have to use . . . multiple choice," says David Vannier, Professional Development Coordinator in the NIH's Office of Science Education. Differences are even arising at the local level: some wealthy districts are preparing for the science test already, while poorer districts in the same state are still not ready for upcoming reading tests.

Some of the criticism of testing, however, may be misplaced. "People like to blame the test developers, who are the same people who make the textbooks, but if people wanted innovative, problem-solving type tests, they would make them," says Vannier. The challenge, it seems, will be convincing school boards to ask.

➲ Throwing the book at them. Science education in the US may be plagued with problems, but at least American students have been given the most comprehensive, lavishly illustrated textbooks in the world.

That is, in fact, one of the problems.

International comparisons show that, while US science textbooks cover more subjects than any of their foreign counterparts, they do so in less depth, and clear explanations are often sacrificed to make room for facts and vocabulary lists — knowledge that is easy to test. Traditionally, science textbook content has been dictated partly by the state curricula of Texas and California, the two biggest markets for school books, and partly by the need to cover the material on as many state tests as possible. The product of these diverse market forces is usually a chimera that looks as if it were created by a committee. In most cases, it was.

In an effort to bring a more positive force to the market, the AAAS's Project 2061 has analyzed the strengths and weaknesses of the current crop of science textbooks for different grade levels and publicized its results. The Project has also convened conferences for textbook publishers, the research community, and policymakers to address the problem. "We've heard from a number of the commercial groups who say that they're going to . . . attempt to make their books better aligned with the curriculum," says Jo Ellen Roseman, Acting Director of Project 2061.

The publishers are probably sincere, but change will nonetheless be slow. Since writing and publishing a textbook is a multi-year process, and most states only buy new books every few years, reformers expect the changes to take at least a decade to reach students.

From the ground up

Instead of trying to implement sweeping changes all at once, other efforts have focused on developing pieces of a working system that can be bolted onto the existing educational framework, then modified and linked together at some point in the future. The *NSES* and *Benchmarks* have given reformers a useful way to coordinate these grass-roots efforts.

Shortly after the publication of the *NSES*, for example, the NIH began creating Curriculum Supplements to nourish the ailing system. The first three supplements focus on the cell biology of cancer, emerging infectious diseases, and human genetic variation. Each supplement consists of one to two weeks' worth of 45-minute lessons, complete with lesson plans, handouts, and computer software. The supplements are designed to fit directly into any curriculum that is reasonably aligned with the *NSES*, replacing more traditional material while still teaching the same lesson. For example, "instead of studying the onion root tip, as fascinating as that is, they learn about cancer. At the end of the day, they get the same idea about mitosis, but they also know a little more about cancer," says Vannier. Providing complete packages that fit into the curriculum also helps circumvent inadequate textbooks (see "Throwing the book at them").

In addition to providing useful health information and fulfilling curriculum requirements, the NIH modules are designed so that students arrive at answers by constructing models and formulating hypotheses. The

agency just released a new batch of supplements and ultimately plans to produce and maintain about two dozen of them. So far, results have been encouraging. Teachers snatched up 25,000 copies of the first batch of supplements, and the NIH has made the materials available online to feed the growing demand. "It's also free," says Vannier, "Teachers really like that."

The additive approach also works well for individual researchers developing their own solutions. Beginning in 1985, biologists at Kansas State University created a set of lessons on radiation biology for public schools. The program ultimately became a popular yeast genetics lesson module known as the *Genetics Education Networking and Enhancement (GENE) Project*. Supplies for the lessons, including yeast strains and a comprehensive handbook, are now sold by Carolina Biological (Burlington, North Carolina, USA), a major educational supply company.

Tom Manney, the physics professor who developed the *GENE Project* before retiring, is optimistic that it will have a lasting impact: "These things keep going. There are a lot of teachers out there who took [*GENE Project*] workshops, who have been very diligent about continuing them and developing them with their colleagues." Kansas State's Beth Montelone, who has picked up and expanded Manney's original project, argues that more scientists should "take a grass-roots approach and try to enhance the scientific knowledge and capability of teachers, as you can by working with them directly. That's where you can have the biggest impact with the least amount of frustration." Using similar tactics, other scientists are already bringing plant and animal genetics into classrooms, using jewel wasps, flour beetles, and fast-growing plants.

As environmental researchers are discovering, these local projects can have a global reach. This principle underlies the Global Learning and Observations to Benefit the Environment (GLOBE) Project, created by former Vice President Al Gore. Students participating in GLOBE perform environmental measurements at their schools, then load the data into the project's publicly-accessible database.

Perhaps the most interesting aspect of GLOBE is that it is not simply a classroom exercise. The data are actually used by earth scientists. For example, the GLOBE Aerosol Monitoring Project, run by Forrest Mims of the Geronimo Creek Observatory (Seguin, Texas, USA) and David Brooks of Drexel University (Philadelphia, Pennsylvania, USA), provides critical fact-checking information for NASA's aerosol-monitoring satellites. The project is based on a sun photometer developed by Mims, which can be built for around $20. By measuring atmospheric aerosol levels and taking fish-eye photographs from the ground, schools participating in the program help researchers corroborate or correct what the satellites see.

"There are probably less than a few hundred ground-based aerosol monitoring sites around the world. Thus a student network of a few thousand sites would provide an incredibly important supplement to present ground-based measurements," according to Mims. He adds that getting teachers to participate in publication-worthy research is an important step towards making them more literate in science.

Regardless of the specific project, scientists could clearly assume a bigger role in reforming education. "My own goal is [to] get at least 15 to 20 percent of the faculty in math, science, and engineering to actually start to work with teachers," says the NSF's Brown, who plans to return to the University of California as a chemistry professor next autumn.

Of course, scientists will have to tailor their approaches to fit their fields; sending your favorite experimental organism into a school or having ninth-graders participate in your research will not be well-received if you study herpes.

Instead, clinical researchers might consider a strategy that has been largely ignored by scientists so far: participating in local politics. Advocates of anti-science positions have had tremendous success with this approach, despite their relatively small numbers (see "In the beginning, there was darkness"). As Case Western's Krauss puts it, "the scientists have to become proselytizers to some extent. Individual scientists have to start thinking about what connections they have within the community and exploiting those and trying to reach out."