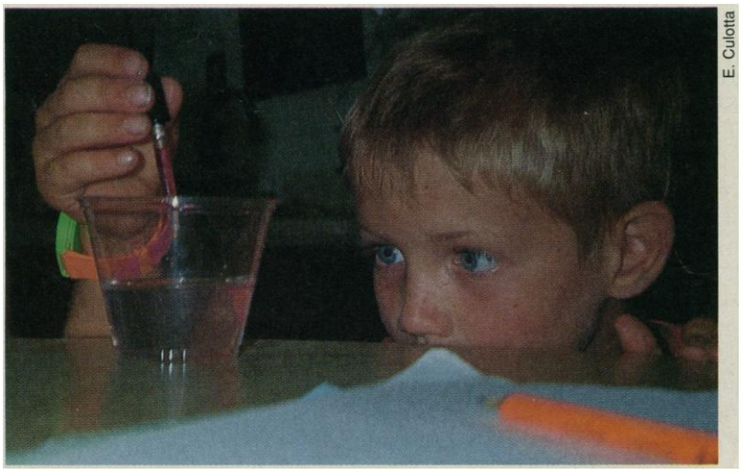
Can Science Education Be Saved?

Three ambitious but very different projects are testing a variety of ways to overhaul an education system that has been getting failing grades

WISCONSIN 9TH GRADER Joel Marino has already decided at age 14 that science is bad news, but he's pretty content with the project his earth science teacher gave him last September: building a working, three-dimensional model of a mid-ocean ridge. To Joel, "This project is more recreational. It's not from the book, you don't have to memorize stuff, and you can work together. Also, it's not due tomorrow. It's not like real science."



E. Culotta

Hands on. *Third graders in McFarland, Wisconsin, learn about dilution through direct experimentation with eyedropper and colored water.*

Joel's dreary image of "real science"—sitting alone memorizing books—will come as no surprise to anyone who has heard the litany of reports on the dismal state of U.S. science and math education. But the scope and ambition of current efforts to attack the problem may be surprising. After 7 years of gloomy warnings about the problem, legions of teachers and scientists are together launching a reform movement the likes of which hasn't been seen since Sputnik. And scientists are playing an increasingly important role in the revolution.

As individuals, scientists across the nation are trying to advise and cajole their local school boards and the teachers of their children to teach science in a more compelling manner. Some scientists have even taken on entire school systems—Nobel prize–winning physicist Leon Lederman is leading an effort to reform science curricula and teaching throughout the city of Chicago (*Science*, 31 August, p. 979). But if there is to be reform on a national scale it will likely require more than the heroic efforts of individuals.

During the past few months, *Science* has looked at three national reform programs, each dedicated to heeding Joel's message, but each pursuing a rather different route to the grail of getting kids intellectually involved in science. One is a long-range effort sponsored by the American Association for the Advancement of Science (AAAS is also the publisher of *Science*); the second, run by the National Science Teachers' Association, is concentrating on more immediate goals; and the third, a project of the National Council of Teachers of Mathematics, is trying to overhaul the content and style of math courses. Will these programs—or any others around the country—succeed? No one can answer that question today. But these efforts to use classrooms as laboratories for education experiments—to permit hands-on, creative, even noisy environments for "real science"—will receive their own grades in the coming years, as local districts decide whether to jump on the reform bandwagon or cling to the status quo.

To Joel, the folks who came up with his plate boundary project deserve—well, at least a B. While the specific project isn't part of a reform program, Joel's teacher, Joe Cabibbo, is a member of a revolutionary cadre of teachers and scientists involved in what is arguably the most ambitious of all the efforts: the AAAS's Project 2061. Named for the year Comet Halley returns to Earth, Project 2061's long-term goal is nothing less than the complete transformation of science, math, and social studies teaching from kindergarten through 12th grade. No part of the present system is considered sacred. Subjects, textbooks, grades—all are under scrutiny, and if this project somehow winds up flunking as a revolutionary movement, it will at least have earned an A for effort.

Project 2061 is developing its vision in three stages: First, decide what students need to know; second, illustrate how they can learn it; third, spread the revolution around. In stage one, teams of prominent scientists delineated what every high school graduate should know about science in a 100-page exposition published in 1989 titled "Science for All Americans." The book emphasizes concepts over data and considerably lightens the burden of facts students must know. Oxidation and isotopes are in; the periodic table is out.

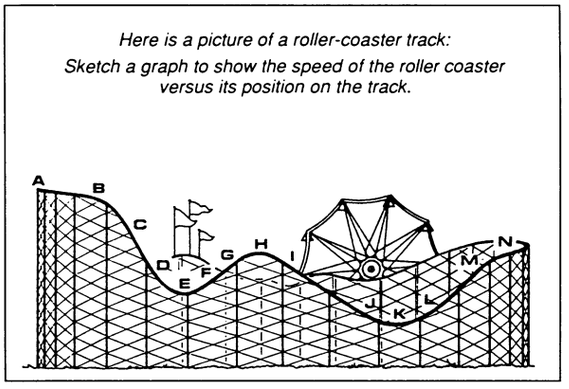
Not every reviewer loved the book. "Still No Beef," complained an editorial in *The Washington Post*, saying Project 2061's "lofty theorists" had put off the work of developing a curriculum. Of scientists' reactions to their colleagues' work, Project 2061 director F. James Rutherford sighs, "They always want more of their own discipline in there."

But many educators and scientists have endorsed both the book and the entire project as a vision of what education could become. "For the first time we have a total representation of what should constitute science education," says Luther Williams, head of education and human resources at the National Science Foundation. NSF has provided more than praise; it chipped in over $2 million for the project's $8.5-million second phase. IBM, the Department of Education, AAAS itself, two private foundations, and state and local governments made substantial contributions.

The *Post*'s criticisms are being answered—slowly—by this crucial second phase, now under way at six sites around the country: Philadelphia; McFarland, Wisconsin; rural Georgia; San Antonio; San Francisco; and San Diego. This time, it's the teachers who are in charge. Their mission: to design a new type of curriculum that carefully builds an accurate picture of the way the world works. With support from scientists, they're translating the concepts in "Science for All Americans" backward into simple ideas children can understand, reorganizing the

book's knowledge into a framework for curricula. For example, a high school understanding of organ systems might begin with the simple statement: "Things go on inside my body that I can't see." That seems obvious, but kids need to thoroughly comprehend it before they attempt to understand body processes, 2061 teachers say.

This type of work, more conceptual than concrete, draws critics such as the director of a smaller science education program, who extended the *Post*'s complaint to stage two and told *Science* that 2061 was too idealistic and slow. But the project was never intended to make change quickly, responds Rutherford. This is to be a thorough and therefore slow revolution. If the models are any good, AAAS expects the rest of the nation to join the revolution, district by district, throughout the decade and later. But Rutherford himself concedes that 1993 will be the watershed year for the project. That's when the curriculum models will be unveiled and a few vanguard districts are expected to start putting the 2061 philosophy into practice. And that's when critics will finally have something tangible to endorse or reject.



Graphic example. *A sample problem from the new math standards. (Source: "Reshaping School Mathematics: A New Philosophy and Framework for Curriculum," National Academy Press, 1990.)*

But even if 2061 were to get the seal of approval from the scientific and education communities in 1993, the project's Achilles' heel may be the decades required by stage three. AAAS knows the risk, and took it, because it felt that every quick fix previously tried in the U.S. educational system had eventually fallen before the multi-headed monster that has parceled out authority across 50 states and 80,000 schools. Reformers might change any one piece of the system—say, by training teachers differently—but the other pieces, such as textbooks, standardized tests and school boards, will drag teachers back to the status quo. So, for good or ill, AAAS opted to try to change the entire system. As Rutherford puts it, "We can't overwhelm that system; we've got to out think it."

But schools can't wait years to improve. While members of Project 2061 dream of the possibilities, other science teachers, through the National Science Teachers Association (NSTA), have spearheaded another massive project called Scope, Sequence, and Coordination (SSC). NSF coughed up an even larger amount for this teacher-based program—$8.6 million—and the Department of Education awarded an additional $2.5 million (*Science*, 31 August, p. 978). Focusing on grades 7 through 12, the project is already in classrooms in three sites—California, Iowa, and Houston—and planning is under way in two more, Puerto Rico and North Carolina.

It works something like this: Seventh graders in Houston don't study the life and physical sciences separately, but instead learn

The Reform Agenda: Emerging Consensus

It may be a time of experimentation for science education, but many trials are testing the same hypotheses. Some common themes are emerging from the patchwork of programs:

■ **Less is more.** It's time for kids to stop memorizing the difference between a type I and type II lever and the names of all the molecules involved in photosynthesis. One study estimated that students encounter more new words in a high school biology book than in 2 years of instruction in a foreign language. "We still live with the Victorian view of school, with minds trained like dogs to memorize things," says Timothy Goldsmith, chair of the committee that wrote a recent report on biology education for the National Research Council. New programs have kids doing more projects and less memorizing.

■ **Teacher power.** Post-Sputnik reforms sometimes took the tone of academic highbrows telling teachers what to do, and teachers have taken much of the blame for education's ills. But the new goal is to boost teachers, not bash them, giving them time to learn science themselves, rather than berating them for their backgrounds.

■ **Science without walls.** Sixth graders in rural Elbert County Georgia don't take science, math, social studies, or reading. Instead, they take one big course—200 minutes run by four teachers—that incorporates all four subjects. A trial balloon floated by members of Project 2061, the course illustrates the push for integrating subjects. Real life problems rarely come labeled as "chemistry" or "math," educators say. How far should such course integration go? Each program seems to have a different answer. Meanwhile, Georgia teachers are still seeking a good moniker for their mega-course.

■ **Do it yourself.** At the end of the school day in inner-city Philadelphia, teachers gather to learn how to separate salt from pepper using static electricity. They're being trained to use an elementary science kit, doing all the experiments their students will do. A staple of the 1960s reforms, hands-on activities are back and better, with a new emphasis on quality—"minds-on" as well as hands-on. Teachers are to be trained more carefully and given the logistic support they need.

■ **Two-way traffic.** Kids haven't understood much of what we've been telling them, in part because we haven't listened to the ideas they already have. For example, research shows that many youngsters don't understand the concept of temperature. They think putting on a sweater keeps you warm because sweaters always exist at a higher temperature. Listening to kids can give teachers clues on how to change such ideas.

■ **Science for everyone.** It's vital to widen the science career pipeline, especially to include more women and minorities. Reformers now also recognize a second goal: producing scientifically literate citizens. Even students who will never become scientists need to understand more about how the world works. New programs are aimed at all students, not just the gifted.

■ **Matchmaker, matchmaker.** Scientists and teachers come from very different worlds. Elementary teachers often opted out of science as soon as they could, but they know their business—kids. Meanwhile many scientists would like to help with science education, but don't know how to do it. "We're like a long-term marriage broker," says F. James Rutherford of Project 2061. "Our job is finding useful work and structures where both sides can interact." ■ **E.C.**

information in thematic blocks. In one, called "Floating and Sinking," students are expected to learn some physics, chemistry, and biology as they try density experiments, including testing gold jewelry for authenticity. The heart of SSC is spaced learning: Instead of getting 1 year each of biology, physics and chemistry, youngsters study each discipline each year so they remember what they've learned, according to Bill Aldridge, executive director of NSTA. Each site is to produce and test course materials for NSTA to distribute; Houston's "Floating and Sinking" has already been sent to other sites.

Also, students are to learn concrete ideas first, then move to abstractions. "The 7th grade textbooks define temperature as the average kinetic energy of molecules. That's not even true at very low temperatures and means absolutely nothing to a 7th grader," says Aldridge. "In 7th grade you should be learning about temperature as it's connected to experience—the difference between heat and temperature, thermal equilibrium. But the materials start with atoms and electrons. That's stupid," he says indignantly.

NSTA coordinates the program and everyone involved is committed to spaced learning, concrete ideas, and fewer facts, but each site has quite a bit of independence. In Davenport, Iowa, for example, 6th graders gather around a specially designed gold and white commode for their science project, "The Royal Flush." Their task: to investigate ecology and consumer choice by testing how well various types of toilet paper disintegrate. That project is a Science/Technology/Society (STS) project run by the Chautauqua program of the University of Iowa Science Education Center. Recently the center hooked up with SSC and was funded this fall to develop 6th grade materials. "Traditionally kids were told, 'Learn this and you'll find it useful.' But it wasn't useful. Now we turn that around," says program director Robert Yager.

Yet another example involves trade-oriented high school juniors in Iowa—a class one teacher referred to as the future cosmetologists of America—who focused on the ozone hole as a way to learn about science. To their teacher's amazement, the students were soon clamoring for information: "What's an atom? What's a molecule? What does pH mean?" The class became the community ozone experts, and college-bound students began to complain that their course was too dull, Yager says.

If all this sounds scientifically sensible, it isn't without its critics. For one thing, the strong STS focus on current events draws fire from Aldridge himself, who believes in principles first, applications second. But he's willing to support Yager in developing the experiment. A second concern is that SSC teachers are being asked to do too much. NSF's Williams, though clearly an overall booster of SSC, nevertheless warns, "In my view, the greatest potential liability of the program is the preparation of the teachers." Indeed, several Houston life science teachers hadn't had chemistry since high school and never took physics, but are now required to teach both. NSTA officials say they've built in teacher supports, such as summer workshops and detailed training sessions. Aldridge himself gave a workshop on "Floating and Sinking" to the Houston teachers. "Most of them hadn't had any physics, and they didn't have any trouble with it," he says.

Ironically, while Project 2061 is criticized for being too slow, SSC gets accused of moving too fast to make real change. Several education experts, including one involved with SSC itself, told *Science* they worried that at some sites the project could become a cosmetic reshuffling of the old curriculum. Aldridge counters that on his advice the NSF funds are conditional on an annual show of progress. If a center doesn't seem to be doing the job, NSF can simply yank it off the project—and perhaps substitute a willing newcomer from a growing pool of states eager to join the program. Also, NSTA officials say they expect change to snowball, as other parts of the system accommodate the project. In conjunction with SSC, California has already begun to use new hands-on tests so unusual that some 6th graders asked to take them again, says Tom Sachse, coordinator of the California site.

Human development. *Philadelphia high school student giving presentation in class taught by a Project 2061 team member.*

While SSC and 2061 compete for funds and are sponsored by very different organizations, after a period of initial jostling over their respective roles the two programs have endorsed each other, with Project 2061 staking out the long-term vision and SSC moving ahead now. But no matter how cordial science educators seem, they've a long way to go before reaching the solidarity of the math community, which is sponsoring a third great challenge to the educational status quo in the United States.

While science educators experiment with course integration and current events, and argue about what to toss out of the curriculum, they watch with envy as the math community calmly describes what to teach and how to teach it. Mathematicians have already wrestled with the tough curricular questions and are moving swiftly toward implementing reform. Last year, math curriculum standards for all grade levels were issued in the form of a 250-page book that was almost universally endorsed. The sequel comes next spring, when another book on professional standards will explain how teachers can reach the curriculum goals.

Part of the smooth progress in math seems to come from the cozy relations between mathematicians and math teachers. The National Council of Teachers of Mathematics (NCTM) developed the standards, but works closely with representatives from the math community on the Mathematical Sciences Education Board (MSEB), an arm of the National Research Council. "The degree to which people agree is amazing," says Iris Carl, who happens to be both president of the teachers' group and vice-chair of the education board.

Mathematicians have an easier time reaching consensus because their field doesn't encompass sub-disciplines as diverse as those in science, Carl says. Also, almost everyone, including parents, believes kids should learn math starting on the first day of school. Of course, most parents think math = multiplication tables, and popular opinions can be a burden as well as a blessing, says MSEB executive director Kenneth Hoffman. "Math came to replace Latin in the minds of some people. It's one of those things you do because it's good for you, to teach you neatness, discipline, and order."

Lovers of discipline are in for a bit of a surprise. The draft version of the professional standards describes a different style of classroom. Youngsters work and talk in groups, explaining problems to each other. Calculators and computers are everywhere and thinking skills and reasoning are emphasized. Kids are to spend less time laboriously plotting points and more time understanding graphs—after a computer does the plotting. It sounds great, but what if the 12-year-olds resist engaging in "mathematical

discourse" and chatter about rap music instead? Be patient, counsel the math wizards.

"I tell people over and over: Don't expect it to happen overnight," says Shirley Hill, former chair of MSEB and professor of math and education at the University of Missouri. "Kids are conditioned otherwise and they're not going to expect math to be fun or relevant all of a sudden. It's a process." The best math teachers already run classrooms like those in the standards, says Carl.

For reform to spread, educators say it's important that all these projects—and many smaller ones not mentioned here—work together, or at least pull in the same direction. "No one will succeed in isolation," says Williams. But while there's much agreement on what teachers should strive for, each program has a slightly different vision of the future. It's not exactly clear, for example, how the new math standards fit with "Science for All Americans," which includes math, but less of it.

And new programs are coming. The National Academy of Sciences, for example, is expected to decide upon a much-expanded role for itself in science education in late December. A few educators who work for existing programs fear the academy will repeat or compete with their efforts, although executive officer Philip Smith insists the institution won't invade any turf. Academy officials are still plotting their strategy and Smith defers any detailed revelations until later this month. But he says they're considering a two-pronged approach, to provide immediate relief as well as long-term vision. And he hints that the academy may tackle undergraduate instruction, an arena where other educators say they'd especially welcome the academy's clout.

For the moment, all sides tend to downplay whatever differences may exist. "It doesn't hurt at all to have different experiments going on simultaneously," says Susan Snyder of NSF's division of teacher preparation and enhancement. "We'll probably never have one single answer."

Snyder and other educators would prefer to focus instead on the momentum for change. The president and National Governors' Association, they boast, have announced the goal of having U.S. students first in math and science by 2000. Privately, though, almost no one thinks that can be done. At least, those involved plaintively conclude, the goal is on the national agenda. The unspoken question: How long will our easily distracted society keep it there? Back in Wisconsin, Joel Marino had the perseverance to complete his model of a mid-ocean ridge with chicken wire, blue plastic, kitty litter, and a mysterious red substance that quickly developed fruit flies. If the education experts succeed equally well with their own models, then Joel—or at least his younger siblings—may one day admit that science and recreation can sometimes be the same thing. ■ ELIZABETH CULOTTA

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Computer Security: NAS Sounds the Alarm

Electronic vandals, viruses, and other malignancies of the computer world are likely to grow more virulent soon, according to a new report from the National Research Council. Indeed, a panel of computer security experts chaired by David Clark of the Massachusetts Institute of Technology warns that unless preventive action is taken, the economy could suffer. In a study titled "Computers at Risk," the panel calls for the establishment of an Information Security Foundation, a private nonprofit body that would set standards, promote research, and review the "trustworthiness" of computer software and hardware. It would require federal support to get started, says one panel member, and after that, it could support itself with membership dues.

"To date, we have been remarkably lucky," the report begins. Money has been stolen by computer—perhaps millions of dollars from credit card companies alone—and "lives have been lost because of computer software errors." But no intruder has been able to "subvert" a critical system. Yet the report warns that "there is reason to believe that our luck will soon run out."

The reason: Little is being done outside the government to reduce the vulnerability of computer networks, even though the nation's reliance on them is growing. For example, no concerted effort has been made to plug the many faults of personal computers, which are difficult to make secure because of the way they were designed. As network linkages grow, more PCs will be connected, and the weak points in systems will increase. "There's no doubt that things get considerably more dangerous when you get unprofessionally administered machines on networks," says panel member M. Douglas McIlroy of AT&T Bell Laboratories.

Most computer and software manufacturers have failed to take the risks of attack seriously, responding to problems as they occur in an "episodic and fragmented" fashion, says the report. And within government, computer security work is concentrated in the National Security Agency, which has been constrained by its secrecy and its national defense mission.

However, McIlroy points out that between 1983 and 1990, the NSA ran an advisory body "outside the perimeter" of secrecy called the National Computer Security Center. It set public standards and served as a clearinghouse for research. This was a valuable service for the handful of companies—like his own AT&T—that wanted to develop better defenses. But this year, the NCSC went back "behind the wire" of secrecy, McIlroy says, and it's not clear that any other office will step in to serve the public. The National Institute of Standards and Technology (NIST) might fit the bill, but the report comments that NIST "has limited technical expertise and funds" to do the work. Congress gave it only $2.5 million for computer security programs in 1990; when NIST attempted to double this budget for 1991, the increase was axed by Congress.

Meanwhile, companies are reluctant to advertise security problems. Their customers often aren't convinced that they're real. Unless they have been stung themselves, says McIlroy, they may not want to bear the costs of improving systems. Many computer users try to get around the problem in a superficial way, using security gimmicks of one kind or another. As a result, hundreds of products are offered for sale, but there's no objective means of judging their quality. The Clark report recommends several actions, in addition to creating a new foundation:

- Establish guidelines for "trustworthy systems" that reflect the consensus of security experts.
- Take a series of immediate short-term actions such as creating emergency response teams and asking vendors to ship products with security systems automatically turned "on."
- Create a system to monitor security breaks and to collect data on them for research.
- Clarify a confusing jumble of export controls and consider relaxing limits on the use of the U.S. Data Encryption Standard.
- Develop and fund a comprehensive program of research on computer security issues. ■ ELIOT MARSHALL