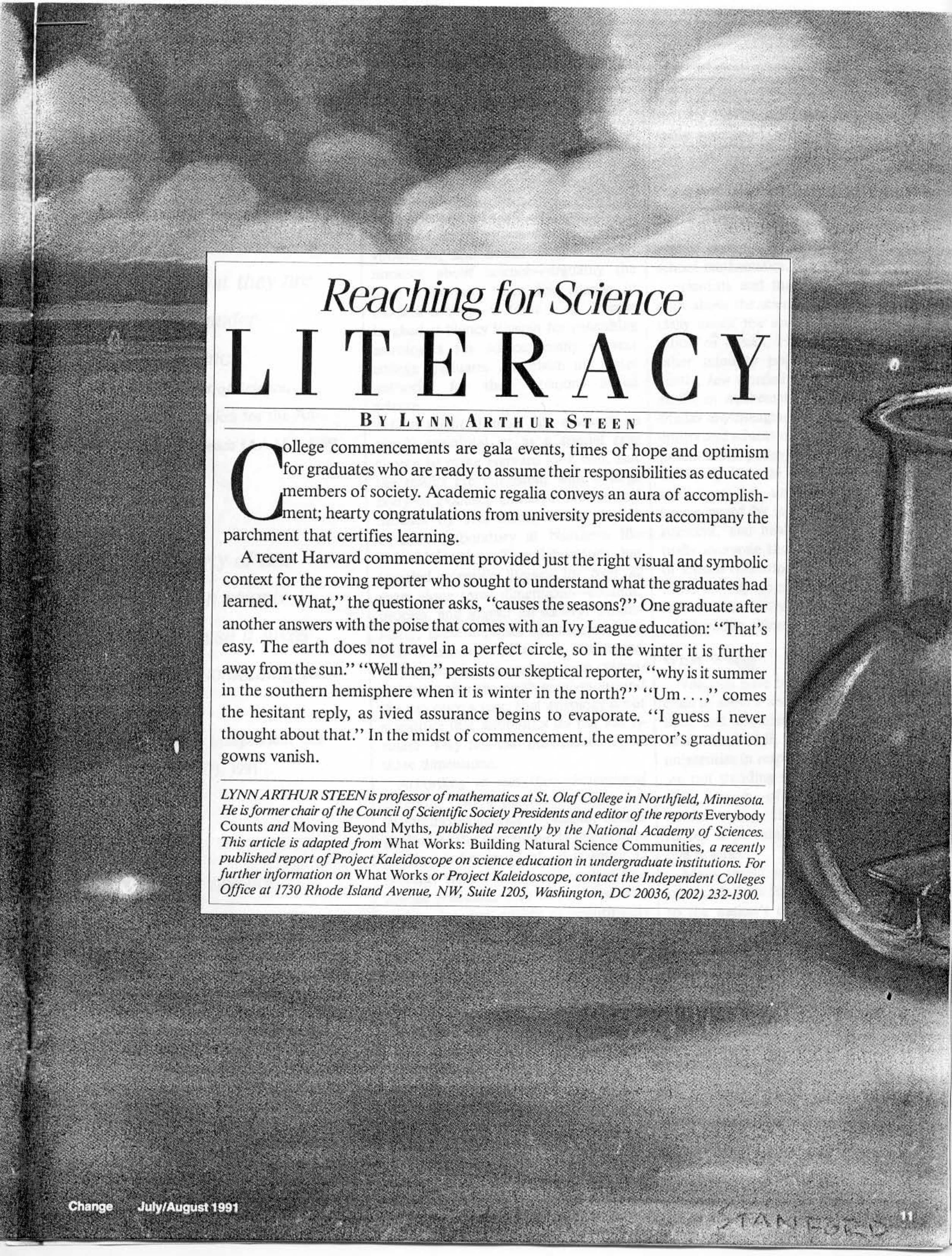

Reaching for Science LITERACY

BY LYNN ARTHUR STEEN

College commencements are gala events, times of hope and optimism for graduates who are ready to assume their responsibilities as educated members of society. Academic regalia conveys an aura of accomplishment; hearty congratulations from university presidents accompany the parchment that certifies learning.

A recent Harvard commencement provided just the right visual and symbolic context for the roving reporter who sought to understand what the graduates had learned. "What," the questioner asks, "causes the seasons?" One graduate after another answers with the poise that comes with an Ivy League education: "That's easy. The earth does not travel in a perfect circle, so in the winter it is further away from the sun." "Well then," persists our skeptical reporter, "why is it summer in the southern hemisphere when it is winter in the north?" "Um. . .," comes the hesitant reply, as ivied assurance begins to evaporate. "I guess I never thought about that." In the midst of commencement, the emperor's graduation gowns vanish.

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Conventional science teaching suppresses students' natural curiosity and leaves them with the impression that they are incapable of understanding science.

—The Liberal Art of Science, American Association for the Advancement of Science (AAAS), 1990

The property of connectedness in science is crucial because it gives the learner something to think about.

—What Works, Independent Colleges Office (ICO), 1991

Numbers are not neutral. They are not inert. They are as alive as we are when they greet us and we greet them: they become what we understand them to be.

—Integrity in the College Curriculum, Association of American Colleges (AAC), 1985

Few who see this videotape vignette miss its message. It conveys vividly the reality of scientific illiteracy among our best-educated students—our future lawyers and politicians, business leaders and school superintendents—who will soon become society's opinion leaders and main actors on issues of energy, environment, and health care. Their ignorance about science—arguably the most important force for change in modern society—is frightening. People laughed at Nancy Reagan for consulting astrologers for advice; many current college graduates can claim no better authority for their opinions about science.

One might dismiss this evidence as purely anecdotal or as a special case chosen to make Harvard look bad. But the results are consistent with a large body of evidence gathered over several decades by Jon Miller at the Public Opinion Laboratory at Northern Illinois University. This laboratory has sampled scientific literacy for over 20 years along three dimensions—content, process, and impact on society. Consistently, these inquiries demonstrate that only a minority of adults understand very basic ideas in any of these categories (e.g., that the earth revolves around the sun once a year; that astrology is not scientific; that antibiotics do not kill viruses). Very few can pass muster in all three dimensions.

According to this three-dimensional criterion, only 6 percent of adults are "scientifically literate." Among college graduates, the percentage is higher, but nothing to be proud of—it is about 17 percent. What's worse, only one in four college graduates who major in science and engineering qualify as scientifically literate, and only one in ten of those who major in education do so.

The data on mathematical or quantitative literacy—numeracy, for short—are equally dismal. Only one in seven high school graduates can solve a simple two-step arithmetic problem involving both adding and multiplying. Two out of every three college mathematics enrollments are in courses normally taught in high school; each year, over 100,000 college students re-study elementary school arithmetic under the euphemism of "developmental mathematics." Indeed, fewer than 10 percent of all college mathematics enrollments are generated by the post-calculus courses normally associated with "higher education" and considered in the European tradition the only legitimate university mathematics curriculum. As far as mathematics is concerned, higher education in the United States has to a large extent become a repetition of high school mathematics.

Scientists and mathematicians worry a lot about the scientific pipeline—especially about the severe under-representation of blacks, Hispanics, and many other minority populations. Until recently, few worried about students' scientific or mathematical literacy. But attitudes are changing on this issue as scientists and educators begin to realize the potential for policy disasters when a scientifically illiterate electorate confronts challenges of unprecedented significance posed by issues of energy, environment, and health. It's clear to virtually everyone that the present system of science education works well only for those *already* committed to science; it fails almost totally in the broader task of educating citizens.

What Works

Volumes have been written about the crisis in science and mathematics education, and countless pilot projects have been launched in schools, colleges, and universities in response. As a nation, we are not standing still. Amid all this activity, much of it frenetic, several themes emerge that provide guidelines rooted in persuasive research and effective practice.

Many recent reports have made recommendations for various "re-"actions to the nation's crisis in science education—reform, refresh, refurbish, regenerate, renew, repair, restore, revise, revitalize, revive—as if what U.S. education most needs is to do things again the way they used to be done, only perhaps better this time. Proposals based on "co-" actions done in association with others—with students, colleagues, and all who support and depend on our nation's colleges and universities—show promise of being more useful. Here are some examples:

Community: Students learn best in circumstances that provide not only intellectual stimulation, but also the social, emotional, and ethical contexts necessary for sustained motivation. Learning science is hard, and although some students have the tenacity to persevere in spite of external hurdles, most do not. Students need to be invited to participate in the shared values and common culture of science; they need to be socialized into the scientific community even as they struggle to learn the methods and results of science itself.

Construction: Students do not simply learn what is taught. Rather, their experiences modify prior beliefs, yielding a scientific knowledge that is uniquely personal. Learning takes place when students construct their own representation of knowledge. Facts and formulas will not become part of deep intuition if they are only committed to memory. They must be explored, used, revised, tested, modified, and finally accepted through a process of active investigation, argument, and participation. Science instruction that does not provide these types of opportunities rarely achieves its objectives.

Connections: To make sense of science and mathematics, students must be encouraged to make connections—whether to social, historical, or personal contexts, to scientific and social phenomena, or to elegant argument and compelling logic. Science and mathematics provide distinctive windows through which students can view the world and see connections to other things they value. Good teaching constantly reveals these connections, both within the sciences and in other areas of life and knowledge.

Continuity: Science and mathematics form a seamless fabric of learning from pre-school years through graduate study and research. The essence of science can be heard in the two-year-old's incessant question: "Why?" College science and mathematics departments both receive students from schools and also prepare teachers for schools. Since teachers tend to teach as they were taught (and not as they were taught to teach), it is vitally important that college science and mathematics instruction exemplify the best standards for teaching.

Programs that work in undergraduate science and mathematics exhibit many of the characteristics of community and connections. The evidence from around the country in all types of institutions is remarkably clear:

- The success of undergraduate research experiences in drawing students into scientific careers is based, to a great extent, on the opportunities such experiences provide students in making connections and constructing knowledge within a community of faculty and student colleagues.
- The remarkable record of the historically black institutions in educating students in science and mathematics—these institutions produce black undergraduate majors in the mathematical and physical sciences at rates 50 percent higher than the proportion of students they enroll—is due in large measure to the strong role that community plays in setting and supporting high expectations for students.
- The programs pioneered by Uri Treisman at the University of California enabling black and Hispanic students to succeed with calculus are centered on special efforts to establish an effective learning community among these students, to enrich the curriculum in ways that maintain continuity with students' personal development, and to make connections with things students value.

One must say as well that when community, connections, and construction of knowledge are lacking, as they too often are, mathematics and science education withers. The evidence is all around us—in the declining interest of U.S. students in science and mathematics. President Bush has called on the nation to reverse this decline and restore the eminence of American mathematics and science education by the year 2000. It is a formidable challenge, one that few scientists or educators believe can be achieved. Nonetheless, this challenge sets a goal worth working towards, which is what is happening right now in schools and colleges across the country.

Mathematics

For generations, mathematics education has marched under the banner of two shibboleths: that mathematics is the language of science, and that mathematics learning develops clear thinking. Unfortunately, the former is at best a partial truth, while the latter is not borne out by research. Nevertheless, mathematics continues to be taught and

The construction of knowledge is also the construction of motivation.

—What Works, ICO, 1991

Building students' well-founded self-confidence should be a major priority for all undergraduate mathematics instruction.

—Liberal Learning and the Arts and Sciences Major: Reports from the Field, AAC, 1991

An able scientist becomes that not because of endowments conferred at birth, but because others cared enough to nurture and inform that person and enmesh him or her in a healthy social interaction that created a sturdy sense of identity.

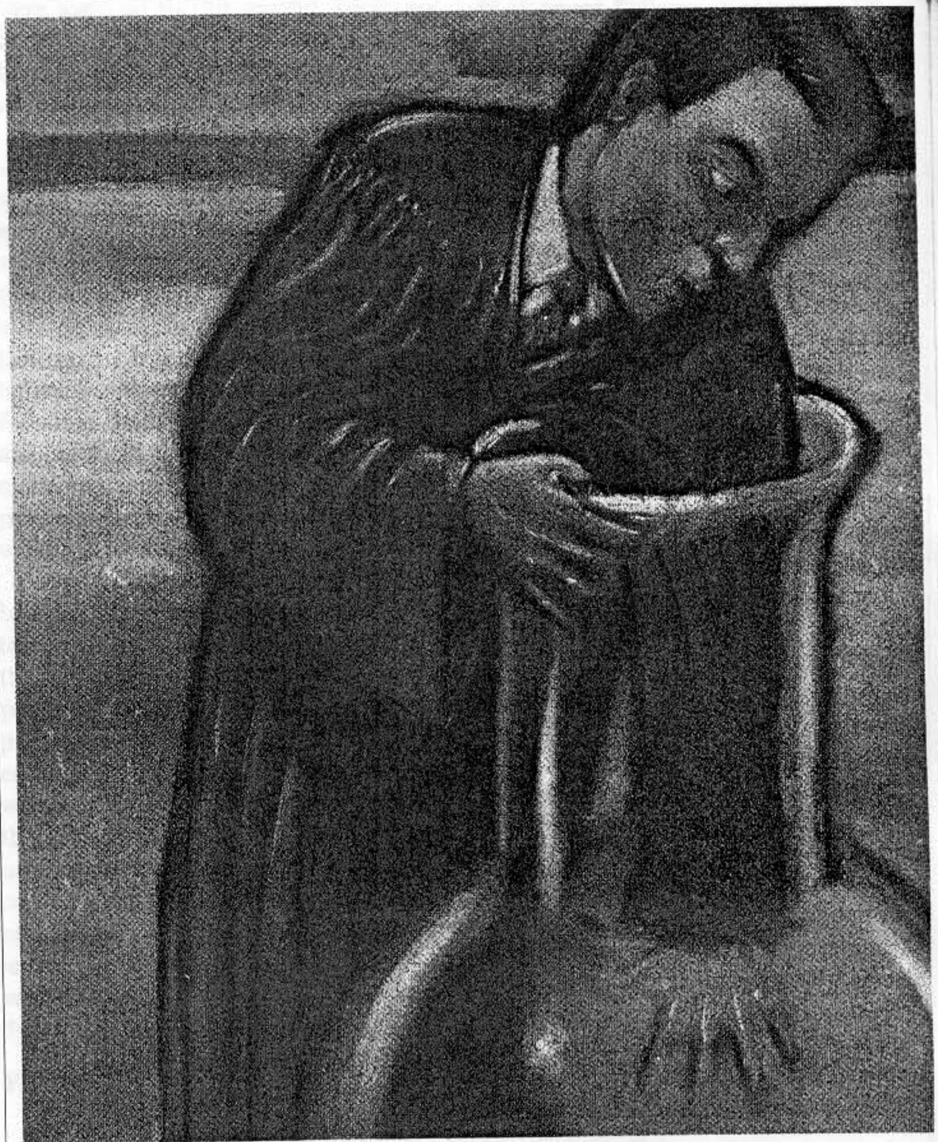
—What Works, ICO, 1991

To believe that one can teach mathematics successfully by lectures, one must believe what most mathematicians know to be untrue—that mathematics can be learned by watching someone else do it correctly.

—Moving Beyond Myths, National Academy of Sciences (NAS), 1991

Unless undergraduate mathematics courses are revised to reflect the impact of computers on the practice of mathematics, students will continue to perceive mathematics as a discipline disconnected from reality.

—Moving Beyond Myths, NAS, 1991



required, often with insufficient attention to the crucial ingredients required to motivate students to succeed in it. The result in far too many cases is education that bestows uneven benefits on different groups within society—white males learn much more, women and many minorities much less.

Examples of mathematical instruction devoid of redeeming educational value are easy to find.

- Large-lecture first-year courses in statistics, calculus, or college algebra in which there is no opportunity for community, connections, or construction of knowledge.
- Required courses in intermediate or college algebra used to meet general education requirements, even though the content of these courses rarely meets any espoused goal of liberal education.
- Introductory courses that filter out of the science pipeline all those who enter without sufficient determination or background to move quickly into advanced courses.

The magnitude of the problem facing undergraduate mathematics can be seen in the stream of refugees fleeing from it to other fields: during the last two decades, the number of U.S. students majoring in mathematics declined by over half, as did the number who went on to receive a Ph.D. Data from international comparisons of college-bound students underscore the challenge facing undergraduate mathematics, as does the high tide of remedial work that has swamped U.S. colleges and universities in the last two decades. In New Jersey, studies of college entrants over the past decade show just 15 percent ready for "college-level" mathematics.

Consensus for Change

Recognizing both the magnitude of

the problem and the seamless nature of mathematics education from grade school through graduate school, several professional societies in the mathematical sciences undertook a major campaign to gain national consensus for a new approach to mathematics education. The emerging consensus is focused on fundamental themes of mathematical power, rooted in research on learning, and tied closely to powerful applications. New standards, which significantly depart from traditional practice, have been promulgated first for pre-college education by the National Council of Teachers of Mathematics, and they are now being implemented in schools and classrooms across the country.

Many of the issues addressed in the new school standards for mathematics instruction are similar to those faced by colleges and universities—notably, how to engage students in learning, how to lead them to construct their own mathematical knowledge, and how to develop authentic, performance-based means of assessment. Colleges face an additional challenge as these new standards are introduced in the schools: In coming years, they will find even greater variety in the quality of mathematics preparation of their entering students.

The most fundamental change in the new school standards—a recommendation supported by both research and practice—is to build the entire curriculum on the assumption that all students can and should learn mathematics. In school, all students will follow a single core curriculum for 11 years, differentiated by breadth, depth, and nature of application, but not by curricular objectives. This represents a sharp departure from the long-standing tradition of two diverging tracks, one leading to higher education, the other to the workforce.

Considerable evidence shows that tracking has, for many students, been a tragic failure. Those in the pre-college track saw only a narrow part of the mathematics necessary for calculus, and, as a consequence, many capable students were turned off to mathematics before they could achieve their full potential. Those who were in the general track learned skills that often did them little good and failed to learn skills needed for higher education. What's worse, far too many minority students were assigned to this second track, not because they couldn't achieve more but because the adults who made the decision thought they couldn't.

Colleges now face a similar challenge—to blur the distinction between science majors and non-majors in first-year mathematics courses in order to provide all students with effective opportunities for the next stage of study. No longer is mathematics just the language of the (physical) sciences; today it is used regularly (in both elementary and advanced forms) in subjects as diverse as business, art, biology, and linguistics. Indeed, mathematics is a universal language of patterns—a tool for analyzing patterns wherever they arise.

High school students rarely see this broad view of mathematics, so it is up to first-year college courses to open their eyes to the enormous power and potential of mathematics—not for the purpose of proselytizing majors but to encourage all students to prepare for work and life in an information age. Although many other forces impinge on undergraduate mathematics—the use of computers, calculus reform, expanding applications, and changing demographics—the need to provide effective first-year courses for all students is without doubt the most urgent priority.

First-Year Courses

College-level introductory courses in the mathematical sciences reflect a deep schizophrenia about aims and objectives. Most students enter college having completed either two, three, or four years of high school mathematics; most remember only a very modest fraction of what was "covered" in these courses. More than a few first-year college students need to start their mathematics all over again, re-learning even primary school skills.

Students entering college confront a bewildering array of mathematics courses, including arithmetic for college students, beginning or intermediate algebra, college algebra or precalculus, elementary statistics, technical mathematics, business mathematics, finite mathematics, mathematics for elementary teachers, "soft" calculus (for business or social science majors) or standard (engineering) calculus. Except for standard calculus, which builds on a

At Hanover College, a course on "Great Theorems of Mathematics" introduces students simultaneously to people, ideas, and history of mathematics, leaving them with an understanding of connections between mathematics and society throughout the ages.

Contact: William Dunham

At Hampshire College, science and mathematics is taught in unified courses, without departments or disciplinary barriers. The approach serves to unify scientific approaches to problems and to ground the study of mathematics in real-world experiences.

Contact: Kenneth R. Hoffman

At Mt. Holyoke College, students with a wide variety of backgrounds engage in a case-study approach to quantitative literacy, living with each case for an entire month to engage the full richness and complexity of the situation.

Contact: Harriet Pollatsek

At Princeton University, a new course called "Geometry and the Imagination" engages students at many different mathematical levels (from novices to majors) in an exploratory, scissor-and tape construction of three-dimensional geometric intuition.

Contact: William P. Thurston

Active Learning

Science and mathematics learning thrives in vigorous communities that help students make connections with issues of importance to them. It thrives when students experience a continuity in their studies that helps them construct their personal knowledge-map of science and mathematics. Despite unmistakeable, very real disputes about the content and organization of science education, it is important to note the widespread *agreement* about these and several other fundamental principles of instruction:

- *Raise expectations.* If more is expected in science and mathematics education, more will be achieved. Students can succeed in science and mathematics, and they will succeed if we expect them to. Colleges must expect all students to become conversant in science and mathematics.
- *Increase breadth.* Most students would benefit from a curriculum that reflects the power and richness of the sciences. Each introductory course should be designed as if it were the last science or mathematics course the students will take—since, for the majority of students, it will be.
- *Use computers.* Just as computers have changed the practice of science and mathematics, so they must also change what we teach and how we teach it. Some topics are just no longer as impo tant as they used to be; others are more important. Scientific computing adds an important new paradigm—computer simulation—to the empirical and theoretical methodologies of science.
- *Engage students.* Students are not empty receptacles waiting for knowledge to be poured into them. Rather, their experiences modify prior beliefs, yielding a scientific knowledge that is uniquely personal. To ensure effective learning, science and mathematics faculty must employ strategies that make students active participants in their own learning, not passive receivers of knowledge.
- *Encourage teamwork.* Employers repeatedly stress the importance of being able to work with a team on common objectives. Most complex problems demand the talents of many different people. Yet science is too often taught in a competitive manner that encourages isolated student work. Science students must learn how to work with others to achieve a common goal: to plan, discuss, compromise, question, and organize.
- *Stimulate creativity.* Students often complain that science is "dull" because instruction stresses problems that are to be solved by one proper method yielding a single correct answer. Nothing could be further from the practice of science or mathematics. Exploration, conjecture, dead-ends, "what-if" analysis, strategizing, and—most important—vigorous argument are the norm in scientific practice. Students need to see this face of science from the very first moment.
- *Reduce fragmentation.* In an effort to organize scientific knowledge into easy-to-learn pieces, courses have been fragmented into chunks selected to illustrate textbook methods. Real problems don't come in compartmentalized form. Fragmentation destroys the methodological unity of science that is its primary source of power.
- *Require writing.* Nothing helps a student learn a subject better than the discipline of writing about it. Writing advances the goal of learning to communicate about science and mathematics; it helps students clarify their own understanding as they try to put ideas into coherent written form; and it provides an opportunity for students who like writing better than abstraction to grow in science or mathematics with a vehicle more suited to their abilities. Writing enhances learning by involving students in the expression of meaning.
- *Encourage discussion.* Most talk in a science or mathematics class comes from the teacher, not the students. In typical courses, students serve as scribes, taking notes and asking occasional questions for clarification. None of this engages the student's mind as effectively as does vigorous argument and discussion. The role of evidence in science and of proof in mathematics can be learned only by doing, not by listening.

Instructions rooted in these practices can energize students and faculty in a special type of shared enterprise—a natural science community. Students enmeshed in such a community will learn not only the knowledge of science, but also its culture, enterprise, and motivation. □

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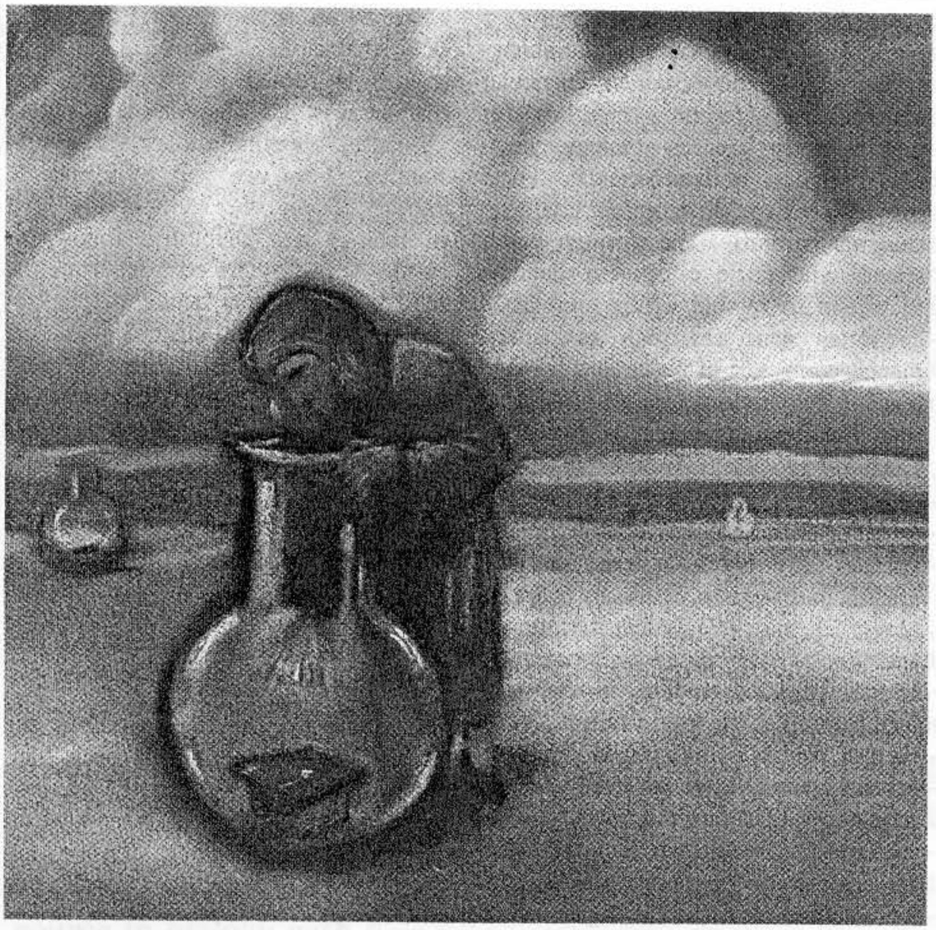
solid four-year preparation in high school mathematics, none of these courses provides effective preparation for further study of mathematics or of other subjects in which mathematics is used extensively. Very few students—well under one in ten—who enroll in anything below calculus ever take any higher mathematics beyond the required sequence in which they first enroll. So, as a practical matter, courses other than standard calculus do not, in fact, serve as an *introduction* to any part of college science or mathematics.

Neither do such courses meet any of the general education goals one might set for them. Students do not learn from these courses about the nature of mathematics, nor about its role in culture and history, nor about its manifold contributions to science, nor about how it can be generally useful in their lives. For the most part, they learn procedures of short-term benefit—skills that employers now entrust to machines rather than to people, and that are quickly forgotten.

The National Endowment for the Humanities recommends in *Fifty Hours: A Core Curriculum for College Students* that all students take at least a one-year (six-hour) course in mathematics that will both "bring students to an understanding of the scope and power of mathematics, its beauty and challenge, and the methods it brings to bear on problems" and "expand choices, providing students . . . the opportunity to give informed consideration to mathematics and other quantitative majors." The NEH report stresses that remediation should not be addressed in the core curriculum. "It would be a grave pedagogical mistake," reports Andrew Gleason, principal architect of the quantitative reasoning program at Harvard, "to try to go over the material that students had failed to master in high school."

Calls for reform in teacher education pose still another challenge to "introductory" course offerings in mathematics. Traditionally, students preparing for careers in elementary education took a special "methods" course in mathematics as part of an undergraduate major in education. As colleges now respond to calls for reform in which students move into teacher education programs at advanced levels after having majored in one of the humanities, arts, or sciences, the question of *what* mathematics prospective elementary teachers should study must be given very high priority. (The answer to the



corresponding question for high school teachers is clear: they need a particularly well-rounded mathematics major.)

Science

In contrast to mathematics, which is a plural noun naming a single discipline, science is a singular noun naming a multitude of quite different fields. This distinction is reflected in the ways we are organized: most undergraduate institutions have separate departments for chemistry, physics, biology, and geology, whereas in all but the largest universities the various parts of mathematics are normally taught within a single department. The plurality of science raises both marvelous opportunities and extraordinary challenges.

Effective responses to issues of energy, food, environment, AIDS, health care, crime, and many other problems facing society require a sound foundation in science. Public policy based on ignorance or misapprehension of scientific knowledge can have very serious consequences, not just for human well-being but for life itself. Society expects and needs both expertise and literacy in science if it is to deal successfully with many of the most pressing problems of our age.

Unfortunately, the gap between society's need for scientific literacy and the ability of our schools and colleges to provide it has rarely been greater. A 1990 study of biology education by the National Academy of Sciences reports that introductory college biology courses provide "notoriously poor educational experiences." More recently, physicists Robert Hazen and James Trefil have excoriated teachers and scientists for creating "a system that alienates students from science from their earliest years." Of course, the science that school teachers teach—particularly its methodology—is to a large extent the science they learned in college.

Making science education work is now the nation's top educational priority. Even President Bush agrees. Yet, in contrast to mathematics, where there is now general consensus on the direction and broad features of renewal, there are at the moment many different and sometimes competing philosophies at work in efforts to improve science education.

At Macalester College, introductory biology for majors and non-majors consists of a 10-week assay to determine the origin of an unknown tumor cell line using the ELISA methodology. Students work in teams on partial solutions, and then share information in order to draw conclusions about the tumor.

Contact: Janet R. Serie

At Mt. Union College, and other places, instructors are developing a new course sponsored by the American Chemical Society intended to provide scientific literacy for people in all walks of life, from home owners to national policy leaders. Called "Chemistry in Context," the course uses applications to major issues of concern to the students (e.g., pollution controls, global warming) and brings in appropriate principles of chemistry on a "need-to-know" basis.

Contact: Conrad Stanitski

At Hamilton College, students are introduced to geology not with a study of basalt, pyroxene, and quartz, but with an intensive study of the plate tectonics of Indonesia, one of the most spectacular tectonic regions on earth. Using complex maps from the U.S. geological survey, beginning students can conduct research with real geophysical data.

Contact: Barbara Tewksbury

Science is a complex social activity. . . . Men and women of all ethnic backgrounds participate in science and its applications. . . . As a social activity, science inevitably reflects social values and viewpoints.

—Science for All Americans, AAAS, 1989

Many students leave their first and only college course in biology with a bad memory of that experience, wondering whether there is any connection between the plants and animals of the natural world and what they studied.

—Liberal Learning and the Arts and Sciences Major: Reports from the Field, AAC, 1991

Disciplinary: One approach, pursued particularly by the various disciplinary societies, is to develop new curricular materials and teaching methods for their respective sciences—biology, chemistry, physics, and geoscience. These projects seek to reinvigorate the courses students currently take through better science and more effective pedagogy; they tend to rebuild within established curricular structures such as departments, courses, and requirements—and teacher education programs—rather than aim at some larger reconstruction.

Multidisciplinary: Another approach, typified by a major project of the National Science Teachers Association, advocates (at the school level) an integrated, multi-year program to teach biology, chemistry, physics, astronomy, and geology in parallel, coordinated courses engaging students in each subject from the 7th grade onward. This pattern, which is followed in most European countries, would ensure a common core curriculum that introduced all students to all sciences and that reinforced learning by repeated contacts at increasing levels of sophistication. (Similar arguments could be made for the integration of science in the first year of college.)

Interdisciplinary: A third approach, exemplified by the AAAS's Project 2061 report, *Science for All Americans,* advocates the teaching of science based on broad unifying themes such as evolution, stability, and change. A variant of this theme recommended by many scientists and educators takes as its organizing principle major science-based issues such as environment, health, and energy. Advocates of approaching science via themes or issues argue that disciplinary divisions are convenient for academic specialists but have little to do with solving scientific problems encountered in real-world settings. Interdisciplinary proponents argue that learning would be enhanced if the curriculum were built on natural areas of student interest, with scientific principles and procedures introduced in context as needed.

Methodological: Many scientists and philosophers stress the importance of understanding scientific methodology, since it is from its methodology that science derives its authority. There is, however, no single scientific method (a point that eludes laymen); although all science is rooted in empiricism, the manner in which observation of nature influences scientific theory varies substantially from one part of science to another. Some sciences, notably parts of biology and chemistry, follow the canon of controlled experimental method in rigorous detail; others, for example geology and cosmology, gather and interpret data as it presents itself, being unable to perform experiments or create controls; still others, especially elementary particle physics, rely heavily on theoretical analysis to develop models that are then tested, often by quite indirect means. Hence, no single discipline can fully reflect the "methodology of science."

Pluralism

The sciences, then, are pluralistic and divided by discipline, by approach to effective instruction, and by the scientific method itself. Trefil and Hazen have argued in their recent book, *Science Matters: Achieving Scientific Literacy,* that the pluralism of science is an educational hazard. Even if introductory courses were well taught—which they often are not—students still suffer by being forced to pick one special science or another, foreclosing any opportunity to see the broad scientific picture. Since science forms a "web of knowledge about the universe," Trefil and Hazen argue that *general* science education provides the key to scientific literacy: "unifying principles" must be part of science courses, whether they are for general education or for prospective science majors.

Although the content and focus of scientific literacy is the subject of considerable debate, there is little disagreement within the scientific community about *how* science should be taught. *Science should be taught as science is practiced.* When this is not done, students come away with what Arnold Arons of the University of Washington has called "received knowledge"—facts and results devoid of understanding. Teaching through practice is important both because active teaching promotes lasting learning and because it is the activity of science more than its results that is most worth learning.

Scientific Literacy

The educational literature has been filled recently with arguments about the proper focus of a core curriculum, about how to balance responsibility to convey the heritage of Western civilization with the evident need to open students' minds and hearts to multicultural and global issues. Unfortunately, science is often on the sidelines in these debates, as if it were not really central to the great issues of liberal education.

But the value to society of scientifically literate leaders goes well beyond the traditional benefits of informed public policy and well-founded decisions. The culture of science has much to teach the men and women who are to be tomorrow's leaders—to learn from mistakes, to share ideas freely, and to rely on data. These and other features of the scientific method are important lessons that all students should learn.

Effective introductory courses will raise the water table for all who study science, thus also helping to build strong majors. First college courses are opportunities for fresh beginnings, a chance for students to see what science and mathematics is all about. What is said of calculus in fact applies to *all* first-year courses in science or mathematics: each introductory course should be a pump rather than a filter in the scientific pipeline.

The shift in metaphor from a filter to a pump conveys subtle implications for faculty responsibility. If first-year science and mathematics courses are designed to filter out weak students, the responsibility of faculty is to set standards sufficiently high so that only the "very best" students pass on to the next tier of courses. If such courses are supposed, instead, to pump as many students as possible into further study of science, then their primary goal must be to provide the motivation and self-assurance necessary for effective learning.

Challenges

With few exceptions, introductory college courses in science and mathematics are total failures. Since the vast majority of students who enroll in them never go on to further study in either science or mathematics, they serve no introductory purpose. Neither do they instruct students effectively in the nature of science or mathematics. At their best, they offer the two-dimensional shadow of a rich, multi-dimensional world; at their worst—which is all too often—they dash motivation and produce another wave of science avoiders ready to convey their attitudes about science to their children.

To be fair, the challenges facing college faculties in this area are virtually overwhelming. Students enter college spread out over approximately five years of schooling in their mathematical and scientific preparation. Although some students are prepared and eager to move ahead with advanced study in specific subjects (e.g., physics, calculus), the large majority would probably be better served by courses that provide legitimate introductions to science and mathematics. Such courses must:

- Engage students in the process of scientific discovery and mathematical practice—actively, regularly, and relentlessly. Passive learning should be taboo.
- Challenge students in a manner appropriate to their preparation. The goal must be to build well-founded self-confidence so that each student leaves the course as a science enthusiast rather than as a science avoider.
- Introduce the power and breadth of science or mathematics, including methodology, fundamental principles, and impact on society.
- Serve as a legitimate and effective transition from high school study to higher courses in science and mathematics.
- Provide future teachers with experience in the excitement of scientific discovery.

It is possible to accomplish goals such as these, but not within the confines of the traditional first-year science or mathematics courses. The examples contained in the sidebars demonstrate the enormous industry, imagination, and inventiveness of dedicated teachers driven by a vision of scientific and mathematical literacy for all students. These courses succeed because students learn the discipline by engaging in it; they grow in confidence as learners, and it is this confidence that equips them for further study either in science or in some other field. □

At Wheaton College in Norton, Massachusetts, students who take a writing-intensive upper-division astronomy course write articles on cutting-edge subjects that are then assigned as supplementary reading in a lower-level introductory course. The authenticity of the author-reader roles helps students in both classes gain a better understanding of the process of science.

Contact: Timothy Barker

At St. John Fisher College, introductory chemistry is now taught in two tracks differentiated not by background in chemistry but by background in mathematics. Each track covers a similar curriculum in order that students from either course can move on to organic chemistry in the sophomore year. The new approach delays the separation of majors from non-majors until the end of the first year.

Contact: Clarence Heininger

At Dickinson College, introductory physics is taught exclusively in a workshop setting so that students' first exposure to new ideas is grounded in the phenomenon itself. Integrated computer software enables direct recording and analysis of data, thus letting students make direct transitions to graphs, equations, and theoretical analysis.

Contact: Priscilla Laws