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ABSTRACT

This essay, based on a national roundtable composed of science faculty, administrative leaders, foundation officers, and program directors examines the gap between advocacy and understanding that increasingly describes the status of science, mathematics, and technical education in the United States. The essay focuses on the capacity of the nation's colleges and universities to meet the demand for citizen-workers who possess a basic understanding of science, mathematics, engineering, and technology. It describes the current status of postsecondary science education, highlighting the limitations of the current system and defining the goals and context of change. The six-point agenda for change includes the following elements: (1) building a research base that documents effective ways to make undergraduate science more accessible; (2) reinstating the mission of science departments to stress the importance of providing students with a real grasp of science; (3) developing strategies for creating partnerships that link two- and four-year institutions; (4) fostering an effective culture of teaching within science departments; (5) making the quality K-12 science instruction an explicit priority of undergraduate science education; and (6) developing learning communities that extend beyond departmental and campus boundaries. Finally, the essay describes the obligations of science education instructors. A list of roundtable participants is included. (MAB)

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PERSPECTIVES

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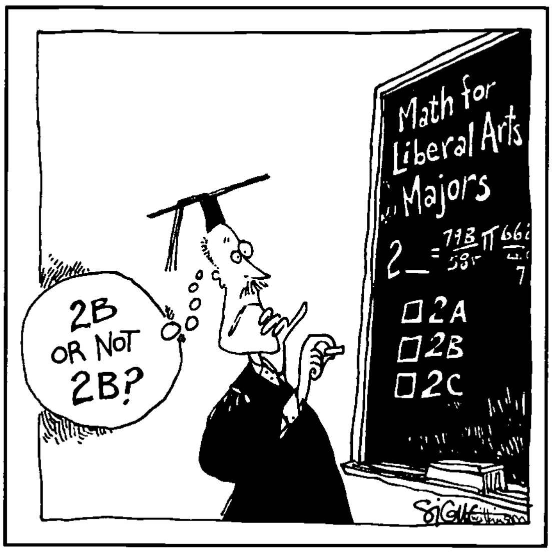

Put a group of liberal arts college presidents around the table, as one foundation did recently, and the result is likely to be a lively affirmation of the importance of liberal learning in general and science education in particular. Give this same group a pop quiz on the principles of science and mathematics, as the host foundation did on this occasion, and the result is more problematic: almost no one passes.

This *Policy Perspectives* is about the gap between advocacy and understanding that has come increasingly to describe the status of science, mathematics, and technical education in the United States. Drawn from the deliberations of a national roundtable convened by the Pew Science Program in Undergraduate Education and composed of science faculty, administrative leaders, foundation officers, and program directors, this *Policy Perspectives* focuses on the capacity of the nation's colleges and universities to meet the demand for citizen-workers who possess a basic understanding of science, mathematics, engineering, and technology: the disciplines that collectively make up what we term "science" in this essay. By "colleges and universities" we mean the full range of higher education institutions—two-year and four-year, public and private—that offer instruction in the core scientific disciplines as part of their curricula. Our focus is on the quality of science education that all students receive in their programs of undergraduate study—including non-majors and those who have traditionally been underrepresented in the fields of science.

We began by asking how undergraduate teaching and learning in science had changed over the past decade. Were there identifiable improvements to either curriculum or pedagogy? Had technology made a difference? Was science, broadly defined, more accessible than before? Had the level of either scientific curiosity or literacy been raised?

Today, there is a broadly shared consensus that students learn best in a hands-on, inquiry-based approach to scientific discovery—and there is a growing conviction within the profession that science curricula and pedagogy ought to reflect this understanding.

Would today's college and university graduates prove to be better informed and hence better able to sort through the legal and policy issues that weave themselves increasingly into scientific inquiry?

Not surprisingly, we spoke of promising starts and remaining journcys, of wills in search of ways. The good news is that a great deal more is now known about the techniques that help science learning to occur. A decade ago, the conversations about what needed to change in undergraduate science education were likely to differ greatly from campus to campus. Today, there is a broadly shared consensus that students learn best in a hands-on, inquiry-based approach to scientific discovery—and there is a growing conviction within the profession that science curricula and pedagogy ought to reflect this understanding.

On many campuses, science education has been transformed, even revolutionized, during the past decade. Science faculty have designed and put into practice instruction that is both better and more inclusive. Much of the shared knowledge that guides these efforts derives from a growing catalog of projects supporting institutional innovation and faculty development. Through conferences, workshops, publications, and other activities, faculty from institutions throughout the nation have fostered and disseminated best practices for the improvement of science curriculum, pedagogy, and learning. Thousands of new as well as substantially revised courses and laboratory sessions have enhanced the educational experiences of literally tens of thousands of students. Through journal articles, textbooks, and conference presentations, the benefits of inter-institutional collaboration have extended beyond the clusters of institutions that have participated in such programs.

The child's rhyme aptly characterizes the current state of undergraduate science education, taken as a whole: "When it is good, it is very good. When it is bad, it is horrid." If substantial progress has been made in a host of settings, in too many other departments or institutions there remains a pressing need for action.

"When it is bad . . . "

On many campuses, however, there remains a sense of separation between what is and what could be. If the mean level of undergraduate science learning has increased during the past decade, this gain has been offset by an even larger increase in the standard deviation. The child's rhyme aptly characterizes the current state of undergraduate science education, taken as a whole: "When it is good, it is very good. When it is bad, it is horrid." If substantial progress has been made in a host of settings, in too many other departments or institutions there remains a pressing need for action. The challenge today is for science faculty, in partnership with higher education administrators, to move beyond the shared understanding of the issues gained during the past decade—to take ownership of the problems and work to solve them in their own terms.

The problem emerges not so much in the quality of majors as in those who enroll in science for more general knowledge. There are too many elementary and secondary school teachers who are frightened by and even resentful of science as a result of their undergraduate experiences; there is too little practical understanding by college-educated parents of the importance of science in either their own or their children's lives; and there are too many college-educated policy makers who bring an alarmingly insufficient understanding of science to the pursuit of their own agendas.

In part, the problem reflects an earlier set of precepts about the purpose of science education. The traditional approach is to conceive of science learning as a process that sifts from the masses of students a select few deemed suitable for the rigors of scientific inquiry. It is a process that resembles what most science faculty remember from their own experiences, beginning with the early identification of gifted students before high school, continuing with the acceleration of those students during grades 9 to 12, fostering in them the disciplined habits of inquiry through their undergraduate majors, and culminating in graduate study and the earning of a Ph.D. Forgotten in this program of selective acceleration are most students for whom a basic knowledge of science is principally a tool for citizenship, for personal enlightenment, for introducing one's own children to science, and for fulfilling employment. Forgotten as well are those students who will become primary and secondary school teachers and, as such, will be responsible for the general quality of the science learning most students bring with them to their undergraduate studies.

The first college-level exposure to science that an undergraduate receives is often in a large lecture class. Whether taught by a junior or a senior faculty member, the impression frequently given is that the "real work" of science takes place well beyond the purview of students in these classes. Although it is widely recognized that an inquiry-based approach to science increases the quality of learning, introductory-level students are often not given to understand what it means to be a scientist at work. Introductory-level instruction frequently gives rise to the image of a grim reaper: "Look to your left, look to your right—one of you will not be here next year." In campus roundtables that have taken place throughout the country, science faculty have at times openly acknowledged their tendency to gear instruction to the top 20 percent of the class—to those students whose native ability and persistence enable them to keep pace with the professor's expectations. The fact that others are falling behind and then dropping out is seen not as a failure of pedagogy but as an upholding of standards. Many students come away from these limited experiences without seeing the relevance and applicability of science to their lives—without appreciating the kinds of questions that science asks, without understanding how a scientist gathers and analyzes data or tests hypotheses in search of answers that give meaning to life.

Defining the Goal

A decade ago, science departments feared they faced a different kind of problem: that gifted young people were turning (or being turned) from the study of science and mathematics in such alarming numbers that a national shortage of research scientists could result. In retrospect, that fear appears unwarranted, given the number of science Ph.D.s unable to find employment in their own or even related fields. The late 1990s have shown that the need to improve undergraduate science education has less to do with replenishing the nation's stock of research scientists than with providing future citizens and workers a demonstrably stronger basic education in science and mathematics.

The outcome we seek is not a lowering of expectations or a profusion of watered-down science for non-science majors. What we do seek is a reduction in the national deficit in scientific understanding, as manifested in the aversion to science that many parents pass on to their K-12 children; in the difficulty that the judicial system frequently encounters in seating juries capable of rendering a verdict on issues involving science and technology; and in the decisions of policy officials who make laws and regulations without concern for the issues that a fuller understanding of science would help to delineate. Even those who do not major in science as undergraduates need to understand science as a mode of asking questions, gathering evidence, and forming hypotheses to account for observed phenomena or behavior. There is a need to impart to more young people the excitement and power that result from considering complex phenomena through the lens of scientific inquiry, and from understanding the uncertainties that attend any attempt to formulate the meaning of what is observed.

Why does such a small proportion of undergraduates proceed beyond the minimum amount of science required for graduation? The likely answer from most science departments is that the quality of education that students receive from K-12 institutions is so inferior that one cannot expect more than a handful of those students to succeed. To ensure "quality out," departments argue, they must have "quality in." From a broader standpoint, however, these departments and their institutions reap exactly what they sow with respect to K-12 science education. Virtually nothing in the reward structure for faculty or for departments recognizes activities to enrich the state of science education in K-12 schools, whether by taking seriously a department's role in training future K-12 teachers or by working with teachers in a local K-12 district. Given the small but steady supply of the kinds of students who naturally command the attention of science faculty, there appears little reason to change in ways that would make science education more inclusive. And there appears abundant reason to champion undergraduate science as the province of "those who can"—those whom an earlier epoch termed the "best and brightest."

We seek an alternative scenario, one that builds on the successes of the past decade to expand the scope of science education. We start with the proposition that most science faculty well understand that there is a problem—indeed, they have concluded that further description is largely self-defeating. Faculty know that the challenges undergraduate science education now faces are neither singular nor simple. They also understand that change will not be easy, that there is no single magic bullet to solve the problem, and that simple exhortations to change behavior will not likely recast communities that have long been accustomed to considerable autonomy.

The Context for Change

We believe that the current state of affairs provides a teachable moment for the improvement of undergraduate science education. In the late 1990s, there are both the will and the capacity among faculty to make science more accessible, and hence more important to the lives of students. The opportunities ahead derive in part from a paradox. On the one hand, the public in general continues to believe in the importance of science, as evidenced by the continuing federal support of scientific research, by the popular acceptance and utilization of scientific discoveries, and by the amount of positive attention the media pay to science and its applications. The advocacy of science remains strong in many respects, even if a deeper understanding of scientific principles and basic technology eludes a growing number of Americans. On the other hand, there is a manifest restlessness on the part of faculty to make science more accessible to students who seek a general understanding of these subjects. It may be that the willingness to change is motivated by the evident restlessness of administrators, who hear student complaints and watch the rate of attrition from science courses. In some cases, the readiness to act may be prompted by the prospect of reduced institutional support in the wake of enrollment declines, though not all science departments face this scenario in the near future. We believe, however, that a majority of science faculty inherently want to do a better job of teaching undergraduates. The progress made during the past decade in the development of new science curricula and alternative pedagogies attests to the ability of science faculty to recast their educational goals and work to attain them. A group that could achieve this much in the past ten years can achieve even more in the next.

The progress made through the past decade in the development of new science curricula and alternative pedagogies attests to the ability of science faculty to recast their educational goals and work to attain them. A group that could achieve this much in the past ten years can achieve even more in the next.

We believe that a growing number of science faculty, partly for their own purposes and partly from the expectations that administrators exert, are prepared to remake science education, affirming once more their twin missions of advancing knowledge and ensuring the general scientific competence of an educated citizenry. An equally compelling change agent will be the general insistence of legislators, board members, parents, and the public that colleges and universities become more responsive to the students they serve. Where once there was a willingness to hand higher education a curricular blank check—trusting institutions to design educational programs in pursuit of the public good—today there is less willingness to credit colleges and universities with knowing what is best for society. Continued public support for science will depend on the ability of science programs to demonstrate that the service they provide actively promotes societal well-being. "Service" has now come to have a broader meaning, and the training of future scientists cannot wholly fill the conception of service that society seeks from undergraduate science programs.

Increasingly, colleges and universities find themselves being asked how, when, in what settings, and through which methods and media their students learn best. There is also a growing recognition that institutions and their faculty will no longer be the only ones at the table when the answers to such questions are given. The question being framed in the minds of employers, funders of higher education, and the public in general is, "What kinds of conversations need to happen outside the classroom to bring about change inside the classroom?" More than before, programs of science must come to think of themselves as working in partnership with forces both inside and outside of their home institutions to develop learning programs suited to a range of societal needs.

It is the kind of conundrum on which science thrives—a problem with boundary conditions. Because they must inevitably shape the solution, those conditions bear repeating.

- Science cannot be made more accessible by lowering expectations; indeed, there is something inherently tough-minded about undergraduate science, requiring both a discipline and a level of mathematical understanding that too many undergraduates seek to avoid.
- Colleges and universities must take more direct responsibility for the quality of pre-collegiate science instruction—in part through the building of effective partnerships with primary and secondary schools.

In Pursuit of an Action Agenda

The search for a set of solutions that conforms to these constraints will necessarily begin with first steps, practical and exploratory in nature and dependent on the intuitions and good will of science faculty for their success. In our own discussions, we came to think of these initial triumphs as "genies": crisp, simple ideas that yield substantial progress toward a desired result. One of the most powerful genies from our own discussion stemmed from the fact that the traditional reward system of a college or university often results in a department's most experienced and capable teachers working only with advanced-level students.

How can a dean or department chair work within the system of rewards to make the teaching of introductory-level courses more appealing to all faculty? A simple answer is to assign such courses greater weight in the fulfillment of individual teaching responsibility. The chair of one science department from our roundtable had successfully proposed this approach to the department's membership, with the result that department members at all stages of their careers now seek to teach the introductory courses. An action of this sort certainly has budgetary implications. But it represents a concrete step to align a department's reward structure more closely with the goal of providing a quality introduction to the academic field—for potential majors and for those seeking a more general understanding. Such an action captures the spirit of a genie—a major initiative, led by science faculty, requiring some investment of institutional resources, to be sure—and promising a major payoff in terms of improving science education for undergraduates.

What is required now are real events—initiatives and programs capable of changing the trajectory that is making science less central to an ever-increasing portion of college graduates.

We believe the recasting of science education in America needs more such genies and fewer top-down, comprehensive initiatives that are long on diagnosis and experiment, short on demonstrable results. What is required now are real events—initiatives and programs capable of changing the trajectory that is making science less central to an ever-increasing portion of college graduates. What we require are initiatives that honor the spirit of our genies:

- Keep it simple.
- Keep it practical.
- Make sure science faculty are in the lead.

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To these first principles we have added three axioms describing the change process itself:

- Cultural, rather than structural, change is the first priority—the kind that yields changed attitudes and hence new behaviors.
- The key agent of change remains the academic department as the bridge that simultaneously links faculty to their disciplines and to their institution's undergraduate curriculum.
- Ultimately, change will also require broad coalitions and collaborations, involving a wide range of departments, institutions, academic disciplines, scholarly societies, and funding agencies, both public and private.

In considering a renewed sense of mission, science departments must be willing to look beyond the language and mindset of their own disciplines, building partnerships with departments in the humanities and social sciences, which for many of the same reasons are reconsidering how to become more learning-centered and more accountable for achieving the learning outcomes they have promised.

Our recommendations derive from these axioms. Collectively, the recommendations stress the need for faculty—working with administrators of their home institutions, and with one another through their departments and disciplinary societies—to define and achieve their shared expectations for science education. We are certainly not the first to identify the necessary levers of change; the 1963 report, entitled *Science in the College Curriculum,* supported by the National Science Foundation, anticipated most of the changes we find most salutary. Thus, what we have in mind is purposeful action in fulfillment of needs that many will find familiar. To underscore this point, we have included suggested genies whenever appropriate.

1. ***Build a research base documenting what works best in terms of making undergraduate science education more accessible and connected.*** Science requires first and foremost a culture of theory and measurement—an ability to specify what success looks like in such a way that cause and effect can be inferred. Much of the work demonstrating the improvement to learning that results from changes in curriculum and pedagogy has been done. What remains is to bring this research together in a form and venue that science faculty can acknowledge. To facilitate the drawing together of pertinent findings, what may be required is a periodic digest of important research on effective learning in particular disciplines. This function is one of several that the disciplinary societies need to perform in greater degree than many do now. One reason that many faculty find it hard to turn their attention to making science more accessible to a broad range of students is that faculty members take their signals for behavior more often from their disciplinary colleagues throughout the nation than from their institutional colleagues. Given this fact, professional societies can play an important role in sending a new set of signals that can help to make science more inclusive. Too often, pleas for the reform of science education have been just that—rhetorical and hortatory rather than specific and evidentiary. It is time to assemble and apply the necessary tools that will make the measurement of desired outcomes truly practical so that new initiatives and experiments can be evaluated in terms of what improvements to science learning they are most likely to yield.

2. ***Restate the mission of science departments to stress the importance of educating a larger population of citizen-graduates to develop a real grasp of science—including those groups that have traditionally been underrepresented in science.*** Such restatements are a necessary prelude to the recasting of departmental curricula and to the expectation that those curricula will provide learning experiences that are inviting and useful to students at both the introductory and advanced levels. Ultimately, such restatements ought to become the basis by which science departments are held accountable for

the outcomes of all students, not just those who seek the scholarly lives of their faculty mentors. In considering a renewed sense of mission, science departments must be willing to look beyond the language and mindset of their own disciplines, building partnerships with departments in the humanities and social sciences, which for many of the same reasons are reconsidering how to become more learning-centered and more accountable for achieving the learning outcomes they have promised. A genie that some science departments have undertaken and many more might consider is to develop programs of science across the curriculum, analogous to the writing across the curriculum programs that currently exist in many institutions.

3. ***Develop strategies and means for establishing operating partnerships that link two-year and four-year institutions.*** What too often gets in the way of a seamless joining of programs, standards, and aspirations is the habit of mind that considers any science or mathematics courses taken outside one's own curriculum as necessarily inferior. Where there are well-established paths of articulation between the two sectors, the obvious answer becomes one of joint planning and shared responsibility. And what works here can then become the basis for a set of triangular partnerships linking two- and four-year institutions with primary and secondary schools.

4. ***Consider ways to foster an effective culture of teaching within departments.*** We repeat the conviction developed in these pages ("Double Agent," February 1996) that the academic department is the most important unit for bringing about cultural change in a college or university. Given that making undergraduate science more accessible and connected requires departmental goals that embrace well-specified learning outcomes, the operative question becomes, "What kinds of partnerships need to develop—within and among departments, and between departments, administrators, and society in general—to make our faculty more effective teachers?"

Is it a matter of moving from teaching for coverage to a kind of teaching that focuses more on cognitive transfer? What will it take to transform the teaching of undergraduate science from stand-up delivery to an interaction that stresses inquiry and discovery? Will it mean abandoning large lecture formats that have endeared themselves to both departments and to administrators because of their evident low cost? Will it mean utilizing technology in different ways, preparing new kinds of learning materials, and abandoning survey textbooks that are "a mile wide and an inch deep"?

For a department to embrace the mission of teaching for understanding, it must willingly be judged by the quality of learning its students exhibit. The first step in a cultural transformation of a department would be for its members to define the discipline-based criteria of learning to which they agree to be accountable. What combination of rewards and incentives would encourage that transformation? Would an announcement that a department's performance in achieving learning outcomes will henceforth be a dominant factor in setting the department's budget send the desired signal, or would it merely provoke a powerful "You can't buy us!" counter-reaction? Would such incentives induce departments to establish benchmarks by which they could measure the quantity as well as quality of learning, for majors and for non-majors?

What about the department chair? What should be his or her responsibility for creating self-reflective departments whose missions are centered on helping students progress in journeys of understanding? Department chairs are instrumental in creating the conditions that enable purposeful experimentation to improve teaching. Chairs ought to have the tools for encouraging members of a department, either individually or in teams, to take on new tasks in pursuit of more open and inclusive undergraduate science experiences. Here the most obvious genies, derived from the experience of several institutions, include ensuring that new courses are evaluated differently from well-established ones; making it more attractive for faculty to teach introductory-level courses by assigning those courses greater weight in the fulfillment of individual teaching responsibility; ensuring that there are regular departmental forums for discussing teaching, course content, and processes; and ensuring that the department's hiring process includes deliberate conversations with prospective faculty about the importance the department places on effective teaching.

One last question linking departmental cultures and institutional incentives: How can a department best foster a culture of teaching that brings many more students "behind the bench"—either by involving undergraduates in research or, more generally, by making sure that students have opportunities to observe and participate in a faculty member's own processes of scientific inquiry and discovery?

5. ***Make the quality of science instruction in K-12 schools an explicit priority of undergraduate science education.*** Only grudgingly have either administrators or science faculty admitted that among their primary functions is the training of those who will become the next generation of K-12 teachers. Rather than disparage the quality of science instruction that their students have received before matriculating in college, undergraduate science programs need to accept their responsibility to provide K-12 schools with teachers who can convey the intellectual excitement of science to children in their formative years.

How can a department best foster a culture of teaching that brings many more students "behind the bench"—either by involving undergraduates in research or, more generally, by making sure that students have opportunities to observe and participate in a faculty member's own processes of scientific inquiry and discovery?

A first step is to put aside the attitude that considers K-12 teaching a loser's last resort; too seldom do higher education faculty or administrators give those preparing for the teaching profession the accolades they deserve as heroes. One way of underscoring the importance of training future teachers is to provide tangible recognition to departments if a certain percentage of their majors or minors take jobs as K-12 teachers within three years of graduation. In addition, science departments in particular could render a service by designing curricula that actually prepare undergraduates for the challenges they will face in introducing the principles and content of science to a younger generation—whether in their roles as teachers of science in K-12 schools or as parents. Too often, the curriculum choice confronting potential teachers—or others not intending to pursue the major—is either the hard-science core or a set of decidedly dumbed-down courses intended for those seeking to fulfill distribution requirements. Those designing science courses for both majors and non-majors should remember that undergraduates will be the parents of a future generation. The positive or negative impressions of science carried away by today's students will be instilled in tomorrow's.

6. ***Develop learning communities that extend beyond the boundaries of individual departments and campuses.*** No institution or department can bring about reform single-handedly. Faculty know instinctively that to depart very far from the norm as it exists among other institutions is to be labeled an anomaly by professional colleagues, scholarly societies, accrediting agencies, and even students. For this reason, any substantial recasting of undergraduate science education requires a coordinated effort among departments of many institutions. There is neither time nor money enough for each institution to solve *de novo* the same problems that nearly all institutions face. Here we think the answer is a new level of cooperation and collaboration, a genuine sharing of experiences, insights, successes (and failures), and—no less important—resources and personnel. What is likely to emerge are better solutions to the problems of measurement, accelerated experimentation, and a community of inquiry with broadly shared goals, standards, and expectations.

Science's professional societies have a continuing role to play in strengthening the ties of collaboration among departments of different institutions. There is also a need for more institutions to engage in the kind of inter-campus collaboration that has resulted from such efforts as the Pew Science Program, Project Kaleidoscope, and the targeted initiatives in support of undergraduate science that have become the special province of the Howard Hughes Medical Institute—all of which have helped to foster shared approaches among institutions in the development of undergraduate science curricula and pedagogy.

7. ***Tell science's stories out of school.*** The present moment is no time to be either shy about or disdainful of public testimony. This story needs to be told—to community groups, to K-12 teachers, to parents and students, to the media, and to officials who make the decisions regarding the funds that flow to scientific research and teaching. Here public relations do matter. To counter the foreboding impression of science education that too often prevails in the public mind requires both presentation and strategy: the former to make science real, the latter to create a citizenry that understands that its own future depends on becoming not just comfortable but genuinely at home with science. These actions can go a long way toward linking the advocacy with the understanding of science; conveying broadly the excitement and the benefits of scientific inquiry must be part of any strategy to enhance the level of scientific knowledge and capacity in society.

We believe there are numerous genies for increasing the public understanding of science and its importance to the well-being of society. Colleges and universities might use the occasion of class reunions to foster parenting-for-science workshops, led by science faculty, to provide insights on how to spark and sustain children's interest in science. The National Council of Teachers of Mathematics, with support from the National Science Foundation, has been working to advance a "family math" program with Parent-Teacher Associations nationwide, helping parents to become informal teachers of math to supplement the instruction their children receive from classroom teachers; other science disciplines could emulate such a program. Science museums have a critical role to play in developing greater understanding of science among K-12 students and their parents, including those who may be economically or educationally disadvantaged. There is work to be done to help representatives of the media understand what are the right questions to ask about science and science education. Another genie, which the professional societies are well suited to bring about, would be to develop or enhance venues such as newsletters, policy statements, and conferences to spread word of the progress made in taking up the agenda of providing a more inclusive and, in that sense, a better undergraduate science education.

When new treatment regimens are developed that offer proven cures for debilitating illnesses, physicians have a moral obligation to apply the findings of medical research to their own practices. The same sense of obligation ought to motivate those of us responsible for undergraduate science instruction.

A Professional Obligation

How will the nation know it is succeeding in making science learning more broadly accessible and connected? Actually, such a good-news scenario is easy to envision:

- a significant increase in the number of "science-smart" people in positions of responsibility and authority, in the arenas of government and policy-making as well as in the private sectors;
- students who exhibit less aversion to science in their K-12 and undergraduate years;
- a steadily increasing stream of teachers into K-12 systems who possess a firm grasp of scientific principles;
- more demonstrated science learning on the part of undergraduates across the full spectrum of postsecondary institutions.

The fact that none of these goals admits readily to measurement at present is itself a statement about the priorities that have driven most undergraduate institutions and their science departments. Defining a meaningful scale of calibration may be the first step to achieving these outcomes. By whatever measure, we have come to see the achieving of these goals as both societal imperative and professional obligation.

When new treatment regimens are developed that offer proven cures for debilitating illnesses, physicians have a moral obligation to apply the findings of medical research to their own practices. The same sense of obligation ought to motivate those of us responsible for the scale, scope, and quality of undergraduate science instruction. Seasoned denizens of the scientific community may want to demur, arguing that the changes we have envisioned are not easy to accomplish, that there is as yet no proven body of data telling practitioners what works best and no sense of reward commensurate with the personal risk and frustration confronting any individual reform effort. Bringing about these changes, they will point out, means changing habits and dispositions that are deeply ingrained. Science faculty, after all, have experienced great personal success as undergraduates in the style of education they now help to perpetuate. Although they remember themselves as being the norm, they were in fact the best and brightest, and they will be reluctant to change a system that served them so well.

However difficult the task ahead may be, we believe that to persist in the future as in the past means making access to science ever more restrictive and, in that special sense, less of a societal good. We concluded our roundtable but not the drafting of this essay before the full results were known of the Third International Math and Science Study (TIMSS)—a broad comparison of schooling and student achievement among some three dozen nations. We too were dismayed that the performance of American 8th- and 12th-graders had fallen farther behind that of comparable students in most of the countries with which the United States sees itself in economic competition. But we were also puzzled by the question raised by a number of analysts when reporting on the meaning of the TIMSS results. How can a nation that leads the world in economic growth and new job creation through the purposeful application of science and technology lag so far behind in the creation of a scientifically literate citizenry? Could it be that the former is, in the end, not dependent on the latter?

We would like to posit a different answer—one that underlies the sense of urgency we have brought to this essay. Part of the disconnect between economic success and scientific learning reflects the fact that this country has long been a net importer of scientific talent from abroad. The United States is a harvester of those school systems producing the students who beat our own students on the TIMSS exams. Part of the answer may lie in the fact that, in the short run, business acumen and a paring back of regulations had a greater impact on economic growth than did the scientific literacy of young workers. And it may be that things have in fact gotten worse in our schools—a price the nation will have to pay farther down the road.

Whatever the answer, it is clear that personal opportunity is increasingly linked to scientific acumen: the very best jobs of the future will go to those who are capable of complex abstractions and disciplined inquiry. The TIMSS results foretell a future in which more and more American young people are missing the boat. And if current trends continue, these young people will not be among those who are advantaged in an increasingly advantage-driven society.

Thus, we come full circle: making undergraduate science education both more inclusive and more rigorous will determine the quality of life in the United States for generations to come. Most of us who practice and teach science know what needs to be done. Most public agencies share our sense of urgency. There is cause for guarded optimism that the media will continue to view science as an important search for knowledge, rather than as yet another subject for exploitation and sensationalism. What is about to be tested is the profession's capacity to make the necessary changes. What remains to be seen, finally, is whether there are enough genies out there—simple, practical steps, involving lots of people and reasonable expectations—to accelerate the process beyond its tentative beginnings.

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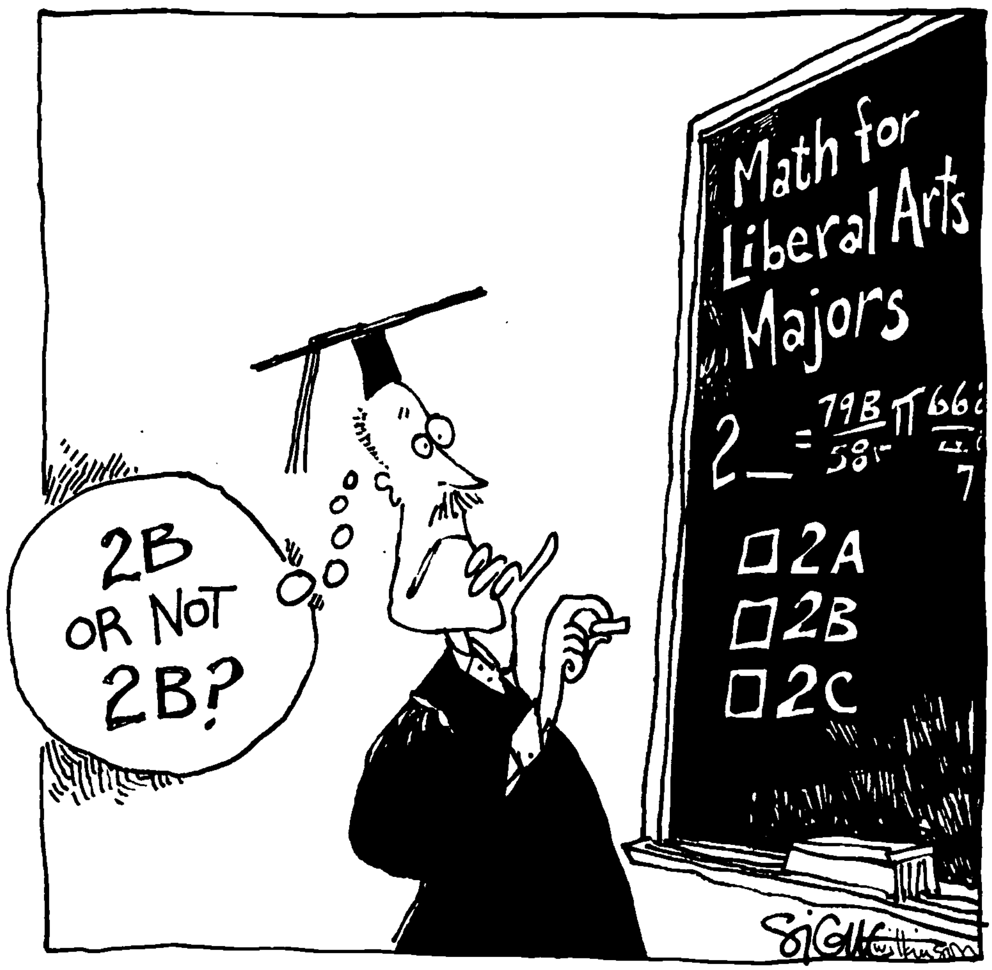

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