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SCIENCE AND SCIENTISTS IN THE TWENTY-FIRST CENTURY

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The American Chemical Society deserves much credit for its energetic and imaginative leadership among professional societies in the area of science education. As we approach a new century, indeed a new millennium, the efforts of all of us in the sciences must be redoubled if our global village is to enjoy peace and prosperity and its environment is to escape further ravages.

The education of scientists for the 21st century is, of course, vital to this vision of a benign future, but it is only a part of a larger educational task. As we begin to discern--however indistinctly--a world in which all human beings will be fellow-citizens, we must work for universal enlightenment. Scientists may make the discoveries, and engineers the inventions, that will shape society in the years ahead, but it will be up to ordinary people--those who vote and through their votes determine government policy--to decide how wisely, or how foolishly, those discoveries and inventions will be used. Only a wise citizenry can make wise choices, and while education does not necessarily beget wisdom, it helps.

At the start of the final decade in this century of unprecedented progress--for both good and ill--it is appropriate, even essential, to examine the reasons why we are concerned about

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These reasons relate not only to our security--of both the national and the economic varieties--nor solely to the effectiveness of our democratic society. Those are important reasons, but an overriding one is our collective conviction that all citizens of this planet must be encouraged to fulfill their human potential. Individual human potentials are not all identical, obviously, but the opportunity to achieve potential must be available to all. Achievement of the human potential of all of us can come only if the integrity of the planet is protected and preserved.

What threatens the planet--the only planet that we have, at least for the foreseeable future--is not only ineffective control of environmental pollution, inability to curb deforestation (especially in tropical regions), and haphazard methods of dealing with the waste from our junk-oriented society, both ordinary wastes and hazardous ones, both nuclear and non-nuclear. The biggest threat is from irrational behavior on the part of societies, their leaders, and the individuals who belong to them. It is through education in general, and especially through education in science and technology, that we have a fighting chance to maintain what former Secretary of State George Shultz called "the sovereignty of the planet."

Human behavior, for the most part, is a manifestation of attitudes and beliefs. With this in mind, we must devote a good deal of brainpower to developing a healthy societal environment that will influence attitudes and help citizens avoid being bamboozled into making foolish decisions.

What is really under discussion here is <u>rational behavior.</u> Let's take a trivial example, related to mathematical literacy, or what is also known as "numeracy." If we had a mathematically literate society--a numerate society--then we would not see the recent proliferation of state lotteries. Unquestionably, these lotteries generate revenue, some of which goes to worthwhile purposes like education and environmental protection. But call them what you will, these lotteries are taxes, and what is being taxed? Gullibility. The day laborer who becomes a millionaire overnight through one big hit on the lottery makes the nightly television news and the front page of the next morning's paper. What doesn't get on TV or make the paper is the fact that this overnight celebrity is outnumbered a million to one by people who bought tickets that same day and <u>didn't</u> hit it lucky. If someone has the mathematical background to analyze his or her chances of striking it rich and then goes ahead and buys a ticket anyway, that person is acting irrationally with eyes open, which is certainly a right that is both God-given and constitutionally protected. But is it justifiable for governments to encourage foolishness, as state-sponsored lotteries unquestionably do? If the harvesting of revenue is the only consideration, and propriety be damned, then why not let the state peddle drugs? (Of course, in some jurisdictions this shocking idea is a fait accompli, if one accepts the prevailing public health view that alcohol is the most widely abused chemical in the United States.

Literacy in science and mathematics reflects our societal values: What we care about, what we believe in, how we treat each other, how we treat our environment. We can measure scientific and mathematical literacy in a number of ways, both wholesale and retail, so to speak. The retail approach is to test individuals; the wholesale, to follow cohorts through the educational process and see what happens to them en masse. Let us consider scientific literacy first from the wholesale point of view.

The diagram diplayed here labeled "The Pipeline" (Fig. 1) represents the hemorrhagic loss of brainpower to science from one cohort of 4 million young Americans followed in a prospective study over a fifteen-year period that began in 1977 and will end in 1992. The purpose of this study was to find out how interest in science persists or wanes in a large, easily identifiable, and reasonably homogeneous group of people over the years.

In 1977, when the study began, these 4 million Americans were sophomores in high school. In some rather general fashion, about 750,000 of them expressed possible interest in a career in one of the natural sciences or engineering. (Note, in passing, that even then 3,250,000 of these 16-year-olds expressed no interest at all in these subjects.) Two years later, as seniors in high school, the scientifically-inclined group had shrunk to 590,000, and just one year later, as entering college freshmen, only 340,000 retained their interest--a 40 per cent drop overnight, as it were. And what happened in college? By 1984, just 206,000--or 5 per cent of the original cohort--actually received bachelor's degrees in science, math or engineering.

The story is not over. The number of B.S. graduates who went on to higher studies declined by a further 70 per cent, to 61,000, and of these only 46,000 actually completed master's degree work. That was in 1986. Two years from now, we will see the final trickle out of the pipeline--fewer than 10,000 men and women with doctor's degrees.

This is not to suggest that everyone should be a scientist, but when existing and predictable shortages of technically learned people are taken into account, it is clear that our needs are not being met even on a replacement basis, let alone for the expansion of science-manpower requirements that are clearly in view. By the year 2,000 we will have a brainpower shortage in this country that will leave something like X,XXX,XXX high-technology jobs unfilled. Perhaps we can import brainpower-- as we import videocassette recorders and automobiles--but we shouldn't count on it; other countries have brainpower requirements too.

A look at Fig. 1, "The Pipeline," shows something that should be obvious to anyone thinking about improving the future supply picture: The only way to increase the numbers in the bottom part of the diagram is to reduce the losses in the top part, and the earlier the better. If losses at each stage of the trip through the pipeline could be reduced by just 10 per cent, the number of bachelor's degrees would increase by two-thirds, the number of master's degrees would triple, and the number of doctorates would more than quadruple.

Mathematical literacy is a curious thing; or, rather, the public's attitude toward it is curious. There is almost a kind of reverse snobbery involved in the average person's willingness--even avidity--to confess that he or she "can't balance my checkbook." People who would bristle at the suggestion that they are not well read--not "literate" in the conventional meaning of the term--cheerfully acknowledge their helplessness when it comes to grasping such basic mathematical concepts as probability or order of magnitude. Here is a case in point:

Addressing a meeting of scientists and trying to leaven the subject-matter with a little humor, I told a favorite story about a university football coach who was desperately trying to maintain the scholastic eligibility of his star player, who had been having trouble with math. The coach went to the head of the math department and wheedled a special oral examination for the athlete which, the professor agreed, the coach could sit in on. The first question was, "What is the square root of 16?" and the player replied, "Four," at which the coach cried out, "Oh, please, please, give him another chance."

Maybe this is funny and maybe it isn't--it is certainly believable--but the scientists in the audience got the point and rewarded me with a hearty laugh. But when I told the same story to an audience of lawyers, there was stony silence for about 23 seconds before a guffaw was heard from the back of the hall--emitted, no doubt, by someone who had a pocket calculator handy.

Referring once again to Fig. 1, the Pipeline is a picture that depends very much on how one looks at it. There is a familiar black-and-white optical illusion that, if looked at in one way, seems to show a beautiful young woman swathed in furs, but looked at in another way, shows a hideous old hag. So it is with Fig. 1: the dark area represents in microcosm the segment of our citizenry with some degree of interest and literacy in science and math, while the white area represents the segment that--to put it mildly--needs work. A long time ago a British mathematician named Lancelot Hogben wrote a book entitled "Mathematics for the Million," preaching the gospel that even in those far-off days before World War II, a decent comprehension of numbers and their meaning was essential to everyone. How much more essential it is half a century later, not only for those who intend to be scientists and engineers, but also for lawyers, journalists, businesspeople and, above all, governmental leaders and those who vote them into--and out of--office.

The National Science Foundation has a vital role in enhancing scientific and mathematical literacy on two distinct yet complementary levels. The first part of this twin mission is to increase the flow of talent into careers in science, mathematics and engineering. The second part is to ensure that lay people understand what science, mathematics and engineering are about--at least to a degree that enables them to make choices based on information and reason. As a government official, I hope that an enlightened public will be supportive of scientific activities that their government underwrites.

For want of better terms, we can designate the smaller, dark part of the Pipeline diagram the "science-rich" sector, and the larger, white part, the "science-poor." Who comprise the science-rich sector? Colleges and universities, parts of industry, and the great national laboratories and institutes involved in research in the physical and medical sciences. Who make up the science-poor sector? Everyone else.

There is a continual give-and-take between these two sectors. The science-poor support the science-rich, with taxes, with purchasing power and with other resources including the sweat of their collective brows. The science-rich minority, in turn, provides the science-poor majority with enhanced well-being of a wide variety of sorts--at least, if it is doing its job. To state it finally and simply, the people in the white area of the diagram pay for what the people in the dark area want to do.

It is fairly well understood, and even agreed to, that the scientific "battle for people's minds" is lost not in the sophomore year of high school--where the 15-year Pipeline study arbitrarily began--but earlier, much earlier, at the middle-school and even the elementary-school levels: the fifth, sixth, seventh grades. Yet the sciences in these grades are woefully underrepresented in the curriculum, and how can youngsters get fired up about an intellectual adventure to which they have never been adequately exposed?

In facing prospects for the 21st century, we must concern ourselves with an enormous stockpile of brainpower that is being lost simply by default--we as a nation are shirking the effort to capture and use this stockpile, and at what woeful cost! The National Negro College Fund has long had a telling slogan, "A mind is a terrible thing to waste," and heedlessly we are wasting millions of minds that will be sorely needed in the years ahead.

I am not talking only about minorities--although the crisis is extreme in this segment of the population; I am talking also about an almost invisible majority of the American people: those of the female gender. In this article I have consistently used the termn "brainpower" rather than the more usual "manpower" to emphasize the fact that males represent less than half the pool from which the next century's scientists must be drawn. And white males, who today predominate in science, mathematics and engineering, are a steadily diminishing brainpower resource.

When one displays the Pipeline data broken down by gender and ethnicity the extent of the problem becomes immediately apparent. Figure 2 shows, on the left-hand side, the dropout rate of females and on its right-hand side, that of males, and Figure 3 shows attrition in ethnic minorities on the left and in the white majority on the right. As a single point to focus on, consider the expected 1992 output of PhDs in the natural sciences and engineering: 9,250 whites, 450 blacks and other minorities--95.6 per cent whites, 4.4 per cent non-whites. In one recent year, of all the doctoral degrees in mathematics conferred by U.S. universities, exactly five went to blacks. This one statistic is a devastating commentary on our ability to tap a pool of minds that we, as a country, cannot afford to waste.

Those who have "made it", intellectually speaking, owe it to posterity to plant some seed corn. It is not enough to turn to the National Science Foundation--for example--and write a proposal for an expensive laboratory machine to enhance one's personal research agenda. That is important, and NSF always welcomes good scientific-research proposals. But there are other proposals that should be written: proposals that will help expand the intellectual horizons of the next generation.

Let me make a few concrete suggestions of what scientific societies and their individual members can do in this respect, and as a chemist speaking to chemists at their national meeting, let me focus on the American Chemical Society.

The first suggestion is to expand the society's educational efforts--to talk to the public as well as to one another. One very effective way of doing this is for individual members to work with teachers in classrooms--at the elementary, middle and high school levels--with a view to imparting to young students the joy that scientists experience in doing science. The young are curious by nature, and if science can be presented as the exciting adventure that it is, a certain number of them will take the bait and enter careers in which they will be sorely needed.

Not only curiosity, but role-modeling as well, enters into any strategy for recruiting scientists and science teachers (who are, in a sense, seed corn for the next generation). Children need role models, and not just the million-dollar basketball player and certainly not the neighborhood drug pusher. The standing, the prestige, of ordinary teachers--many of whom are <u>extra</u>ordinary people--is essential in stimulating interest in science on the part of schoolchildren.

The young are curious and emulative by nature, to be sure, buy they are not cats or parrots; they are pretty perceptive, and if the educational table to which they are invited offers junk food unappetizingly presented, it will not take them long to perceive this fact--and to react in a way that any reasonable person would react. The young, though they may not always seem so, are also pretty reasonable.

What I am leading up to is a plea for broad curriculum reform, not only in chemistry, but across the board. The fact that reform is needed can hardly be questioned; all one has to do is look at where American pre-college students stand in comparison with contemporaries in every other advanced country of the world, and some countries not so advanced. But what kind of reform? As a first step, I believe, we should develop and explore alternatives--what I call the "Procter and Gamble" approach: you put out five or six high-quality products and let the market choose. Different school districts, different colleges and universities, may choose different curriculum approaches, but if all these curricula cover comparable ground, the desired results should be achieved. A number of curriculum reform plans have been advanced--ChemCom in the field of chemistry, the American Association for the Advancement of Science's Project 2061 and the National Science Teachers Association's Scope and Sequence project in broader areas of science--and in the course of time will be tested.

The leadership of professional societies must carry the message to Washington. As a government official, I hesitate to use the "L" word, but yes, the professional societies should lobby the government about perceived national needs in research and, especially, in education. Finally, these societies should "network"--to use a vogue word from the computer era--interacting with one another and such prestigious umbrella organizations as the National Academy of Sciences, to see to it that the intellectual leaders of this country devote a fraction of their time and effort to improving education at all levels.

Industry, too, can play a role in applying pressure for the improvement of science education. The National Science Foundation sponsors a number of projects--Presidential Young Investigators is one--in which science-oriented industrial organizations can play a valuable role. These projects are not a one-way street, with industry simply passing out largesse; science teachers hired for summer work at industrial plants under NSF-sponsored arrangements have made such valuable contributions to companies they have visited that now it is customary to write a "no-raiding" clause into these part-time hiring arrangements.

Many industrial concerns work with their city and county school systems not only as a public service, but also as a matter of enlightened self-interest. A local plant's labor force for the year 2000 and beyond is being educated right now in the school across the street or down the block. The more relevant the education those children get today, the better workers they will be tomorrow.

Industry, too, is no stranger to the "L" word--for good or for ill. A healthy development would be for industry spokesmen to continue--and to broaden--their efforts to influence national policies in science and science education. What is true of the local plant and the local school board is equally true on the national scale.

So far this discussion has focused on pre-college science education, and rightly so, because this is where the big leakage occurs in the Pipeline. But colleges and universities are not immune to problems of educational adequacy, particularly in the undergraduate years. In the remaining years of this century there will be a huge influx of funds from the federal government and the business sector into college and universities, specifically to address problems in science education.

One of the principal problems has to do with the irrational behavior of colleges and universities in dealing with the young minds that are the raw material of their production process. Speaking as an academician myself--a tenured professor of chemistry on leave from the University of Wisconsin--I view my chosen line of work as talent development. Yet all around me I see my colleagues in Academia busying themselves--and taking great pride in--weeding out freshman and sophomore students rather than guiding and developing them. This is irrationality run wild. Colleges and universities spend a great deal of effort pre-selecting students--so much so, in fact, that the Justice Department has accused some of them of forming a cartel to control admissions. So what happens? Having weeded out the unqualified beforehand through scholastic achievement tests and the like, the colleges proceed immediately to winnow out a substantial proportion of those who made the grade--either by flunking them outright or by making the major field they favored at admission so unattractive that they switch career paths in midstream. This accounts to some degree to the fact that (Fig. 1 again) 70 per cent of college students who expressed interest in science at matriculation changed their minds before graduating--if indeed they did graduate.

Some thoughts about things that must be done, which Donald Kennedy, president of Stanford University, addressed to his institution last April are pertinent:

> The first [he said] has to do with the attention we give to our students and especially with the centrality of undergraduate education. The joint product character of our enterprise has long been a source of strength to us. Teaching and research are both important but the relative weight has shifted over time, as the relatively new term "research university" suggests. It is time for us to reaffirm that education--that is, teaching in all its forms- -is the primary task and that our society will judge us in the long run on how well we do this....
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> I close this passage of painful but well-meant criticism by quoting a distinguished colleague, deeply knowledgeable about Stanford and full of love for it. When asked what he thought our most serious problems might be, he said, "Just one. I would wonder whether this excellent research-oriented faculty in this splendid student body, with its research interests, haven't drifted toward a kind of unwritten agreement: 'You don't bother us too much, and we won't bother you too much, either.'"....
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> I believe we can have superb research and superb teaching too, and in support of that proposition, I offer the example of the pertinence, programs and [???] countless individual colleges who have excelled in both. [BASSAM: SUGGEST YOU CHECK THAT LAST SENTENCE FOR ACCURACY.--B.H.] <u>We need to talk about teaching more, respect and reward those who do it well, and make it first among our labors.</u> [Emphasis supplied.] It should be our labor of love and the personal responsibility of each one of us.

May I offer one more idea for academicians to ponder: Look at the outcome of the educational process; look, if you will, at the quality of the end-product of our particular production line. What does it mean to be the holder of a bachelor's degree from a research university, a comprehensive university (what used to be called "teacher's college"), or a liberal arts institution? What does it mean? It means, of course, that one has fulfilled the requirements for graduation, but does it necessarily mean that one is really qualified to be a productive member of society?

I have alluded, so far, to the responsibilities of school boards, college administrations, scientific organizations, and industry. Now it is time to talk about the responsibilities of the federal government, which is the only entity that cuts across all boundaries. For a long time--let us be frank about it--the federal government shirked its obvious duty to see to it that every American child gets an equal opportunity for an education adequate for full participation, but now we begin to see a consensus developing on the need for just such equal opportunity.

What we need, as America approaches the 21st Century, is a national strategy for a set of uniform goals and standards, and agreement on the components of change and reform that we must develop--components related to curriculum content, staff and staffing, conditions of teaching and of learning, and finally resources of both the human and financial varieties.

The first step in this direction came last year at

Charlottesville, Virginia, the home of Thomas Jefferson, who must certainly be regarded as our first "education President." There at the university that Jefferson founded, the present education President and the state Governors agreed on a set of goals, a notable one being to bring American students to the head of the rankings in science and mathematics by the year 2000. Admittedly, this is an ambitious--one might even say unachievable--goal, considering our place in the rankings today, but in response to skeptics one can echo words from the late President Kennedy's call for men on the moon in the sixties:

"While we cannot guarantee that we shall one day be first, we can guarantee that any failure to make this effort will make us last."

What are the national goals we need to deal with? They have to do with student achievement, with teacher qualifications, with the environment for learning, and with quality of the curriculum. In the development and achievement of these goals, a heavy responsibility rests on the shoulders of what I have called the science-rich sector, but the responsibility does not rest there alone. The science-rich sector can develop high quality curriculum material, but that material must be applied effectively and equitably, and that is the responsibility of all of us as citizens.

When we talk about <u>national</u> standards, we are not talking about <u>federal</u> standards; that is, not about something imposed from above by Washington, but about something agreed upon and implemented across the country. And when we talk about standards, we must talk also about means for helping students meet those standards. Educational standards should be guideposts for the young on their way to full, productive citizenship; they should not be gates to lock people out of the promised land.

So where does the National Science Foundation stand in all this? Consider the basic function of NSF since it was founded thirty-five years ago. It is to the other sciences what the National Institutes of Health are to the medical sciences--a fountainhead of leadership in research. And that is what my part of NSF--the Directorate of Science and Engineering Education--is doing in large measure: encouraging through grants and contracts with the academic community the development of more effective ways to teach science, engineering, and mathematics. Literally hundreds of imaginative projects are under way, aimed at finding new ways to capture and retain the interest of students--at all levels, from kindergarten through college--in the sciences. NSF grantees are experimenting with computerized learning, with teaching by film and television, with innovative textbooks and a broad spectrum of other pedagogical techniques. Not all of these will pan out, just as not all the therapies conceived by NIH grantees panned out, but the payoffs from successful experiments will more than pay the total bill--as indeed has been the case many times over with the billions invested in health-directed research through NIH.

Nothing is going to happen, of course, without the informed consent and enlightened concern of the public that must pay for educational reform and that, in the end, will benefit from it. That raises a question for the future to determine: Will the American people rise to the occasion? A wry anecdote from the public-opinion polling business comes to mind.

A pollster--so the story goes--approaches a man in the street and says, "I am from the So-and-so Polling Organization, and I would like to ask you this question: Is the greatest problem facing America today ignorance or apathy?" Without a second's hesitation, the man in the street replied:

"I don't know and I don't care."

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