Exhortations for Enhancing the Quality of Science and Technology Education

1992 MRS Spring Meeting Plenary Address

Bassam Z. Shakhashiri

I want to share with you some important convictions about the status of science and engineering education in the United States. These convictions are the basis for much of what I, and so many others across the country, believe should be happening in terms of reform.

To me, the purpose of education is to enable individuals to fulfill their human potential. The ultimate goal of reform is not only to influence the quality of science and technology education, but to influence all of education. Improvements in science and technology education are but vehicles to bring about fundamental, comprehensive, systemic changes in our society.

In my judgment, the country now faces a situation far more critical and more consequential than what we faced in the immediate post-Sputnik era. Let me give you three reasons.

First, in the past 35 years or so, the population of the United States has increased by about 50 million people. This is the approximate population of Great Britain and twice the population of Canada. You might say, "So what, that's a big number. What does it mean?" It means that we have more students to teach now and that we need more qualified teachers at all educational levels. So, the first reason can be summarized as change in scale. All societal institutions are sluggish in responding to changes of that magnitude. Education, especially, continues to be sluggish in responding to that change.

A second reason the situation is more critical and more consequential now than in the late 1950s and early 1960s is that for the United States to maintain its international pre-eminence in science and technology, in the global economy, in the arts and the humanities, and in all walks of life, we need a good supply of scientists and engineers coming through the educational system. After Sputnik, the summer teacher institutes, the curriculum development projects, the graduate traineeships and fellowships, etc., were aimed at increasing the flow of talent into careers in science and engineering and were largely successful. Now, we face an alarming situation in terms of maintaining the flow of talent into those careers.

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The third and, in my judgment, the most important reason is that we now live in a more advanced scientific and technological society and we must pay attention to the education of nonspecialists in science and in technology. Our fellow citizens must be able to distinguish between astronomy and astrology, to deal successfully with the complex issues related to animal rights and pollution control, and to understand why burning the rain forests in South America is bad for the global environment, even if it is good for the local economy (just as burning down forests was good for the economy in this country about 100-150 years ago).

National Twin Mission

We are embarked on a twin national mission. One part of the mission is to maintain the flow of talent into careers in science, technology, and mathematics, and into careers in *teaching* science, technology, and mathematics. This has been the traditional mission of institutions of higher education and of federally funded programs.

The other part of our twin mission is to see to it that the public at large is literate in technology, science, and mathematics. All of us in the technological and scientific communities should pay special attention to this part. Let me try to make this point as forcefully as I can by offering an analogy from sports. Just as we have professional baseball, basketball, football, and hockey players, we also have sports fans. Without those sports fans, the entire professional sports enterprise would be nothing. So we need professional scientists and science fans. We want those fans to be physically and mentally fit, not simply passive spectators. Hence the twin mission—to have a good flow of talent into science and technology careers and to make the public at large literate in science and technology.

Figure 1, a well-known display, shows the persistence of interest in the natural sciences and engineering among a population of high school sophomores which in 1977 numbered 4 million. Of those 4 million high school sophomores, 750,000 expressed an interest in science, math, and engineering. Of those 750,000 the number dropped to 590,000 when they became seniors in high school. Among those that went on to college one year later, the number dropped down to 340,000. That's a 40% drop in one year. 206,000 received baccalaureate degrees in the natural sciences and engineering in 1984; 61,000 enrolled as graduate students; 46,000 received master's degrees; and by the end of this year, fewer than 10,000 of those 4 million high school sophomores will earn PhDs in science, math, and engineering. As you can see, there is a great deal of leakage in this pipeline. It's not just leakage—it's a hemorrhage in terms of the loss of talent, of peo-

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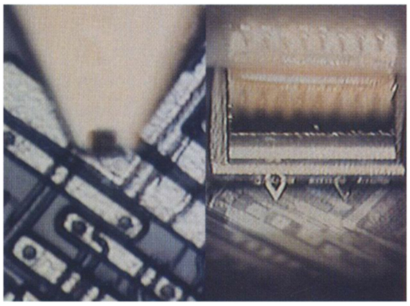

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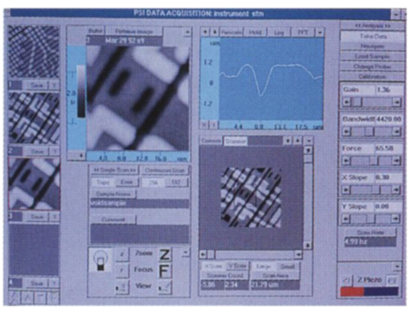

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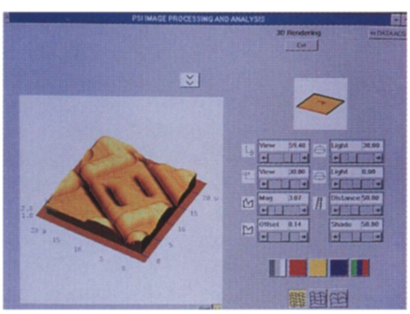

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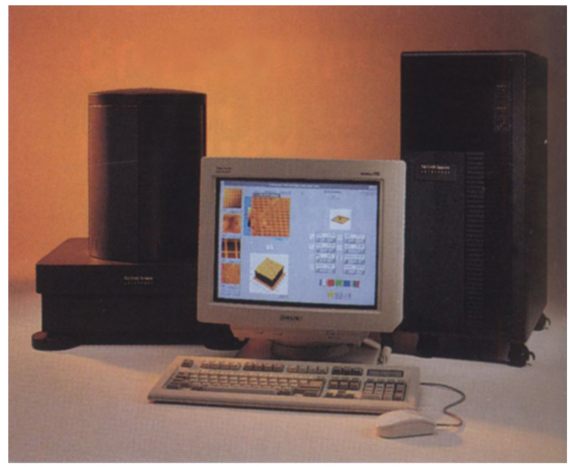

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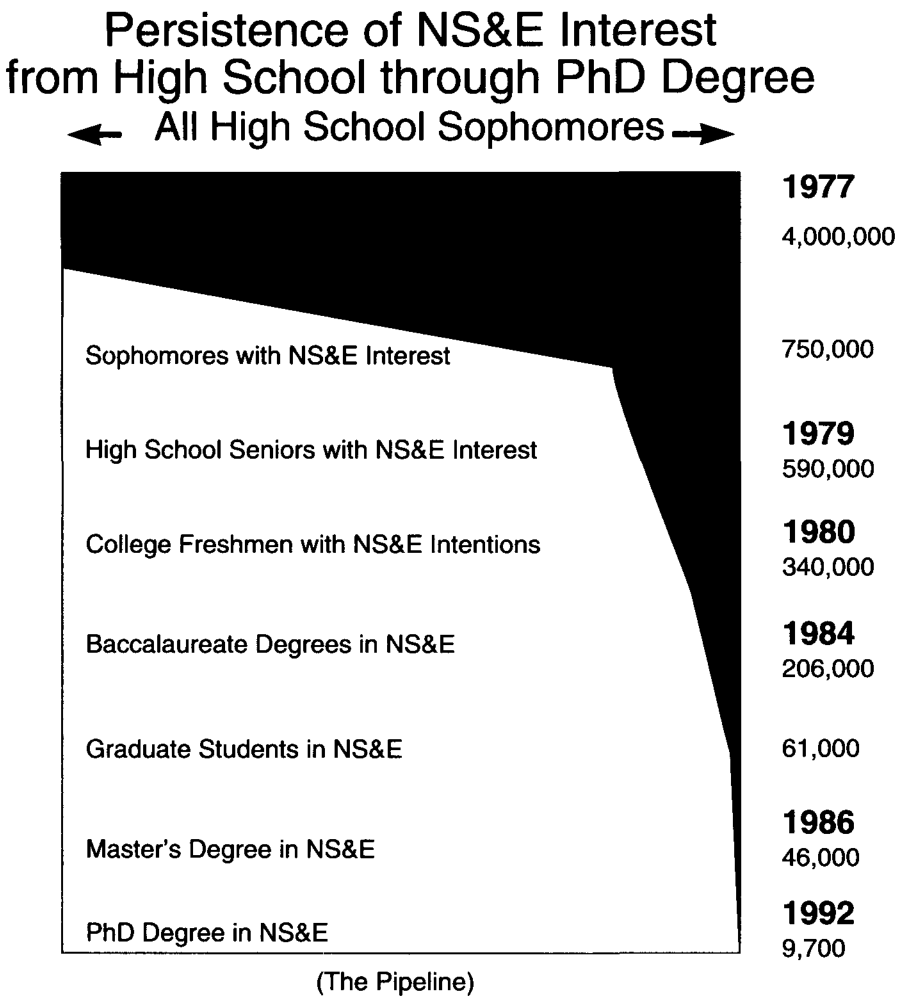

Figure 1. Persistence of natural science and engineering interest from high school through PhD degree in the education pipeline.

ple who are interested in pursuing careers in science, math, and engineering and who, for various reasons, drop out.

It's fairly well understood, and even agreed, that the problem does not develop in the sophomore year in high school, but much earlier. High school is when the students vote—when they express their opinions and act on the attitudes they have developed since kindergarten or perhaps earlier.

Look again at Figure 1. It's so easy to focus on the shaded part of the display, the science and technology rich sector. I would like you to focus on the unshaded part. That's the general public. We need to focus on this group in special, targeted ways.

Who is in the science and technology rich sector? Colleges and universities, parts of industry, the national labs. Who is in the science and technology poor sector? Everyone else. And those of us in science and technology owe something to them. There are many valid intellectual reasons why we should be concerned about society's understanding and appreciation of science and technology and I have alluded to few of them already, but there is one more reason. The people in the unshaded part of the display *pay* for what those of us in the shaded part want to do. That's why it's incumbent upon us to pay attention, in very targeted ways, to society's understanding and appreciation of science and technology. And that's why efforts should be aimed at providing high-quality educational opportunities for all students at the K-16 level. (I think it's artificial to consider K-12 education separately from post-secondary education.)

An immediate goal for us is to articulate what we mean by literacy in technology, science, mathematics. I want to show you a display of the 4 million high school sophomores by gender (Figure 2). This figure looks like an unsymmetrical champagne glass. (You know in science, math, and engineering, we love symmetry; it's aesthetically pleasing.) We have to make this display symmetrical. There are two ways to accomplish that and one is unacceptable. We've got to change both slopes in the right direction. Please, don't forget about the people in the unshaded area, the people that are part of our twin mission. Federal agencies, and industry as well, invest heavily in the people in graduate school, the people whose representation here is indistinguishable from the stem of this champagne glass. We should continue with that investment by providing additional opportunities and by devising effective recruiting and retention strategies. More importantly, we should also develop strategies for the people in the unshaded area.

The display of the same 4 million sophomores by under-represented minorities (Figure 3) is, again, a very sad commentary about our value system as a society. How can we, as a society of achievers in science and technology, tolerate this kind of display, where a good segment of the population is denied the fulfillment of their human potential?

When I speak of literacy in math and science and technology, I mean literacy for everyone—for lawyers, for business people, for everyone in our society—not just for those who are college-bound or are planning to go to graduate school.

We in the science and technology rich sector of society are not very clear about what we mean when we say someone is literate in science, technology, and mathematics. We even tend to downgrade the efforts of people who take it upon themselves to articulate such statements. We need to go beyond communicating science and technology only to each other. We do a wonderful job of that through conferences, publications, literature, fax machines, electronic mail, and in other ways. But we do a poor job of communicating science and technology to the public at large. And we tend to blame the media for not carrying out the message. But, we ourselves are not clear about what that message is, and we should take the responsibility ourselves for articulating what we mean by literacy in technology, science and mathematics.

Let me be very blunt. Institutions of higher education do not value contributions to science communication as much as they value contributions in research. Federal agencies, including the National Science Foundation, put a high premium (until recently, the sole premium) on contributions in research. In fact, on receiving a grant from a federal agency, the first thing recipients usually do is to buy time off from

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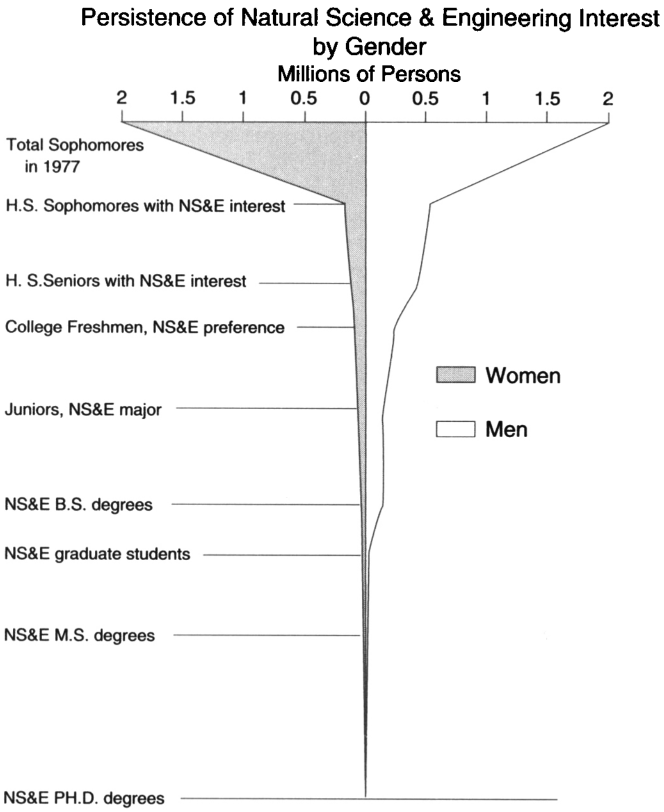

Figure 2. Persistence of natural science and engineering interest from high school through PhD degree by gender.

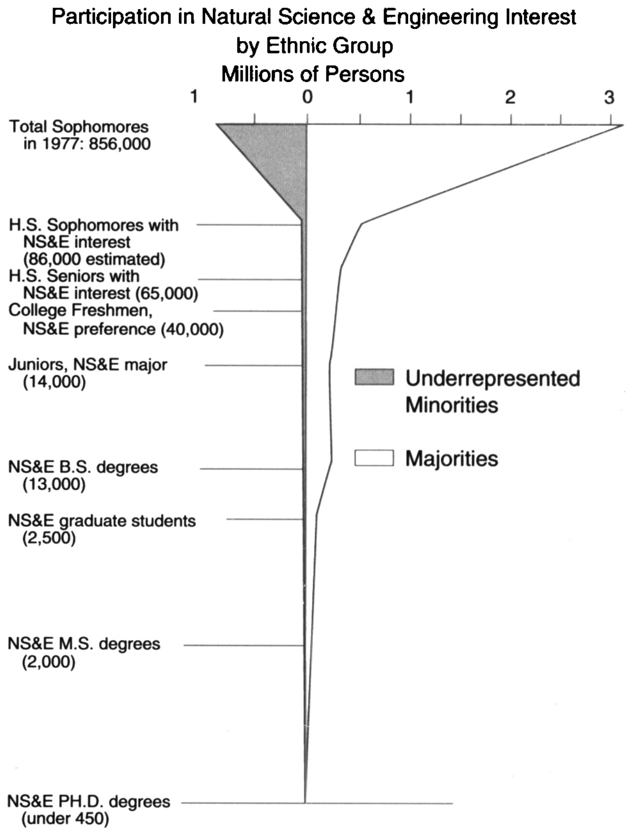

Figure 3. Persistence of natural science and engineering interest from high school through PhD degree by ethnic group.

teaching. That says something about our values!

What *are* those of us in the shaded area really doing? We are attempting to fulfill our human potential. That's why we do research. That's why we enjoy the challenge and struggle that lead to accomplishment. But we should also be concerned about the fulfillment of the human potential for the people in the unshaded area.

Communicating Our Values

When I was in Washington, I was often asked, "Dr. Shakhashiri, why do you want support for education in science, math, and engineering?" I used to answer, "Why, it is for the same reason that we want support for research in science, mathematics and engineering." Most people would nod their heads and say, "Well, yes, that sounds good." But a few people would ask, "What is that reason? Why do the federal agencies provide support for science, math, and engineering research and education?" Tax dollar support is provided for three traditional reasons. One is to ensure national security, another is to seek economic security, and a third is to maintain our effective democracy.

I'd like to ask each of you a personal question. Did you go into science or engineering because it is good for our national security? Or because it is good for our economic security? Or because you believed in the effectiveness of our democracy? I say you didn't. You and I went into science and engineering for many *personal* reasons, not the least of which is enlightenment.

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You are curious about the world we are in. You ask questions. Why is the sky blue? Why do soap bubbles float? Why do we see whitecaps when the wind blows on a body of water? Is the color of those whitecaps in any way related to the color of the stuff that floats up in the sky? Why do flowers and other plants blossom in the spring? Why do the leaves change color in the fall? How does the microwave oven work? How does a suspension bridge get put together? What is a microchip? How does it work? How does the scanner at supermarket checkout counters work? Why do some credit cards have holograms? We ask questions, questions, questions. We are naturally curious and we want to be enlightened.

We go into science, math, and engineering for the joy of learning, for the fun of it—fun in the best sense of the word. I'm not talking about cheap thrills such as bungee jumping from a hot air balloon or bouncing into a wall with a Velcro suit.

Of course, we went into science because of the promise of a job. We sensed that our society valued scientists and engineers. There were national fellowships and scholarships and we saw opportunities for personal economic security.

In testifying before the Congress or talking to a governor or the president of an institution, if I said, "We need support for science, math, and engineering research

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and education for personal enlightenment and joy," I'd get laughed at. But, if I said, "We want support for reasons of national and economic security," they would understand right away. You can see the problem we have in communicating our value system to the rest of the society. We need support for all these reasons. And we first have to state to ourselves what the reasons are and then communicate them effectively to the rest of the population. I'm talking about our values, what we care about. I'm talking about affirming what it is that we do and attempting to communicate that to the rest of the population.

Let me give a couple of examples to help bring out the points I'm talking about. Today's newspaper, the April 27th *San Francisco Chronicle*, contains a story by a distinguished science writer, David Pearlman. He talks about Humboldt's complicated fault system. He writes in some detail, and at a comprehensible level, what the faults are, where they are, with diagrams, illustrations, and so on. You might say this type of communication is his job. Well, I think it is our job also. When a natural phenomenon occurs, when a scientific discovery is announced, or when a major technological breakthrough is achieved, all of us should use the occasion to communicate with the public at large. This should be a continual process and not just a series of incoherent presentations and discussions.

Another story from the same newspaper on the editorial page, "A Bigger Bang," talks about the discovery of previously undetected variations in temperature of about one part in 100,000, which helps explain why stars are not arranged in perfect symmetry in an ever-expanding universe and which produces evidence why gravity is the basic force shaping the universe. Of the 27 lines here, one-third of them are about the prospect of a Nobel Prize for the Berkeley astrophysicist who heads the NASA-funded team. The Nobel Prize is important, but is it worth one-third of the editorial?

The very same story as reported in *USA Today* says: "The numbers are so numbing that they may produce nothing more for many people than a big ho-hum. For after saying 'Wow!' what else can one say about NASA's announcement Thursday that it had discovered the possible origin of the universe in cloud-like structures, one of which is 59,000,000,000,000,000,000,000 miles across. Indeed the most immediately comprehensible number is the cost of the cosmic background mission launched in 1989—$400 million." Then, a survey at the bottom asks, "Should NASA be studying the origin of the universe? Why?" There is a toll-free number to call and express your views.

We need to be concerned about communicating what we do and how we do it, not only to ourselves but especially to the people in that unshaded part of the display.

Outcomes of Formal Education

Unlike research, the outcome of formal education is not open ended. We can identify the characteristics and attributes of a person who will get a bachelor's degree from the University of Wisconsin-Madison or from Berkeley, MIT, or Stanford. Thus, we should clearly state the expected outcome of the educational process. In research we don't define the outcome. That's why we do research—to find out what we don't know. Education should be outcome-oriented.

> It is almost criminal to have courses in science and technology without a "hands-on" lab component.

What does it mean to be the holder of a bachelor's degree from Stanford, from UW-Madison, from any institution in the country? What does it mean to be the holder of a high school diploma from any high school in the country? It means that the students have fulfilled the graduation requirements. That's what the university president or high school principal says at commencement: "By the authority vested in me, I hereby confer upon you the degree based on the certification of the faculty."

But, what is the purpose of these requirements? We need to pay attention to the contents of what is taught. I'm suggesting something fundamentally different, which is to look at what we want to do, not only how we want to do it. We need to articulate the characteristics and attributes of the students who are "subjected" to the educational process. For example, recipients of bachelor's degrees, in addition to being trained in a technical area, should have developed good communication skills, be able to tell the difference between right and wrong, know how to exercise good judgment in making decisions, and have a sense of responsibility to society.

Here is a brief list of some of the components of reform in education. We have concerns about staff and staffing and about the conditions for learning. This is a euphemism for, among other things, having to tolerate courses in science and technology that don't have a lab component. We have a proliferation of such courses at the high school level and at the collegiate level. In my opinion, it is almost criminal to have courses in science and technology without a "hands-on" lab component. We should also be concerned about governance issues and both human and financial resources.

National Strategies and Standards

We need a national vision and strategies. We need goals and standards. We need to be concerned about student achievement, about the qualifications of teachers at all educational levels, not only at the high school and elementary levels. What is being done to prepare the PhD candidate to become a faculty member? Next to nothing is being done. We have to reexamine the purposes of graduate *education*, not just graduate *training* in research. We need to be concerned about the environment for learning, the quality and effectiveness of the curriculum. We need national standards established at each grade level, K-16. Then we need to help the students achieve those standards.

I want to say something about standards because the word gets misused. People use standards as a gate to lock others out. I'm talking about defining standards and helping students achieve those standards. Until recently, numerous faculty colleagues from across the land who taught introductory college science and math courses would brag about how many students they were flunking. That says something about our value system. I believe we are in the talent development business, not in the weeding out business.

That's why we need to develop a vision of what we want our students to do while we are in contact with them. How do we influence students so that 10 or 15 years down the line, their attitudes manifest responsible behavior, even though they may not become scientists, engineers, or mathematicians?

Here's a goal: the President of the United States and all 50 governors have said that by the year 2000, U.S. students will be first in the world in mathematics and science achievement. This goal is the fourth of six national goals set at the 1989 Educational Summit held in Charlottesville, Virginia (see sidebar).

What do most of us do when we hear a statement of this goal? We laugh. That's the best way to make this goal an empty goal. This is the best statement we're going to get from the politicians, so we have to use it as a rallying point to bring about the necessary fundamental, comprehensive, systemic changes. In 1961, the President identified a national goal—by the end of the decade we shall send a man to the moon and bring him back safely. That, too, could have become an empty goal, but it was used as a rallying point. Many important scientific and technological developments occurred as a result of that goal statement and the accompanying will to achieve it. By the way, what happened after we sent a man to the moon and brought him back safely? We sent more men to the moon and brought them back safely, right? And maybe someday we will send a woman to the moon and bring her back safely. Sending people to the moon and bringing them back safely could have become an empty goal. The 1961 national goal captivated the country and engaged government, industry, and education in pursuing a mission. This pursuit spawned countless advances in technology and caused a lasting change in attitude in our society.

That's what the 1989 national education goals are about. They are rallying points. The fourth goal is singularly aimed at science and mathematics achievement. Let's use it to help accomplish changes in science and math education. Let's not make it an empty goal. What should we do in the year 2000 after the test results are announced and we are first? Do we have big demonstrations and beat on our chests and yell, "We're Number One! We're Number One!"? That's not what this goal is about. Yes, there may be problems with this goal, but it's the only thing that we can get from the politicians. I'd use this goal to help achieve literacy in science and technology among all students graduating from high school and from college in the year 2000.

We need national strategies and we need to quickly develop a will to implement those strategies. We shouldn't be surprised if some years down the line this becomes an international strategy because the problems we're talking about are not peculiar to the United States.

Here are a few elements to be included in any viable strategy. We need to have literacy in science, technology, and mathematics for all students. We want the best preparation for careers in research and in teaching. We want to increase representation. We want to support experimentation and we want to generate change—fundamental, comprehensive, systemic change. Incremental change will not do. We want assistance for implementation from the federal government, from the private sector, from industry, and from wherever we can get it.

An Example of Fundamental Change: Curriculum Reform

Let me suggest a specific approach to curriculum changes. Before I do that I want to salute Rustum Roy and his colleagues for their outstanding efforts in promoting the development and use of science, technology, and society(STS) courses. Roy's article in the March 1992 *MRS Bulletin* is a must.

> **NATIONAL EDUCATION GOALS**
>
> By the year 2000: (1) All children in America will start school ready to learn; (2) the high school graduation rate will increase to at least 90%; (3) American students will leave grades four, eight, and twelve having demonstrated competency in challenging subject matter including English, mathematics, science, history, and geography, and every school in America will ensure that all students learn to use their minds well, so they may be prepared for responsible citizenship, further learning, and productive employment in our modern economy; (4) U.S. students will be first in the world in science and mathematics achievement; (5) every adult American will be literate and will possess the knowledge and skills necessary to compete in a global economy and exercise the rights and responsibilities of citizenship; and (6) every school in America will be free of drugs and violence and will offer a disciplined environment conducive to learning.

I believe that the K-16 curriculum can have three strands consisting of mathematics, health, and the environment. Why mathematics? Mathematics is the underpinning for everything we do in science and technology. It cuts across all disciplines and all levels of education. About four years ago the National Council of Teachers of Mathematics developed a set of standards to change the way mathematics is taught. We should learn what these standards are and find out where they should be implemented and, if we don't like some of them, how we can change them.

Under health there are at least three areas—human biology, nutrition, and drug education. What does human biology have to do with materials science? Kids of all ages are curious about changes in their bodies. This is a vehicle to capture that curiosity and to nurture talent. Material scientists can exploit developments and advances in health and treatment of disease to communicate the applications of pacemakers, magnetic resonance imaging, radiology, buckyballs as potential transporters for specific drugs, etc.

Tremendous advances in the nutritional sciences never find their way to the classroom or to the public at large. Food processing and other related technologies have greatly affected diets, but are yet to affect dietary habits. Biotechnology is likely to have great economic effects as well as health effects. Literacy in technology should go beyond learning how certain processes work.

There is some emphasis in our society on drug enforcement, but we should expand our educational efforts about drugs. Considerable damage accrues to society when individuals and groups become addicts or behave irresponsibly under the influence of drugs. Drugs are materials whose effects and contradictions on human beings are known, by and large. Technological advances have helped drug design and manufacturing. Such knowledge and understanding should be used to educate and to alter behavior for the betterment of individuals and society.

Why the environment? Issues of the environment provide multiple and integrated ways to teach science. Learning about the ecology of the planet requires principles of chemistry, biology, physics, botany, earth science, and engineering. Including environmental issues and phenomena (global and local) in systemic reforms of the K-16 curriculum can strengthen the preparation for responsible citizenship.

I submit that the biggest obstacle to curriculum (and other) changes in materials science, chemistry, physics, and in all the disciplines is that we don't want to do it. Think about it. We are the agents of change. We are the custodians of knowledge. We have the intellectual prowess to buttress existing efforts and to launch new ones. If we put our minds to it and target our efforts, we can bring about the required fundamental, comprehensive, systemic change. But the single biggest problem is inertia.

Now, I would like to speak to the graduate students in the audience, to their mentors, and to the people in industry. You should be encouraged to pursue scholarly

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activities, not only in the laboratory but in dealing with the development of curriculum materials and teaching strategy for the purpose of bringing about this change. An important report came out of the National Science Foundation earlier this year. It's called *America's Academic Future: A Report of the Presidential Young Investigator Colloquium on U.S. Engineering, Mathematics, and Science Education for the Year 2010 and Beyond.* This outstanding group of young academic researchers says that we need to alter our culture in order for the research enterprise to survive, and for the quality of the human condition to improve.

Conclusions

Many reports say that U.S. students do not do as well in science and mathematics on international comparison tests as students from other countries. I don't believe for one second that the talent in this country is any different than the talent anywhere else around the world. Yet, these reports are telling us something about our educational system and about our society—something to which we should pay special attention.

The nature of supporting institutions of higher education and supporting research in this country is likely to change drastically in the next 10-25 years. We should take charge of the change process and make it a change for the betterment of the human condition. What's at stake is the quality of life on the planet, and those of us in the science and technology rich sector of society have a special obligation that goes beyond excelling in our subspecialties. We in the science and technology community have a large responsibility because of our knowledge. We have to pass it on and call for rational and wise behavior from both individuals and societies. □

***Bassam Z. Shakhashiri,** professor of chemistry at the University of Wisconsin-Madison, was, in 1983, the founding director of the Institute for Chemical Education. From June 1984 through June 1990, he served in Washington, DC as Assistant Director of the National Science Foundation for Science and Engineering Education, where he rebuilt education programs that had been essentially zeroed-out in the early 1980s. His efforts set the NSF education budget on a $600 million trajectory for fiscal year 1993—up from about $100 million in 1988.*

For Further Reading...

EVERYBODY COUNTS—This report examines mathematics education as all one system, from kindergarten through graduate school, and it treats all the major components of the system, from curricula, teaching, and assessment to human resources and national needs. It identifies problems, charts a general course for the future, and also outlines a national strategy for pursuing that course. Report #COUNT7 is available from: National Academy Press, 2101 Constitution Avenue, NW, Washington, DC 20418.

SCIENCE FOR ALL AMERICANS - PROJECT 2061—Six reports were written as part of the first phase of Project 2061, a long-term, multiphase undertaking of the American Association for the Advancement of Science designed to help reform science, mathematics, and technology education in the United States. These reports consist of an Overview Report (#89-015) and five panel reports: Biological and Health Sciences (#89-025); Mathematics (#89-035); Physical and Information Sciences and Engineering (#89-045); Social and Behavioral Sciences and Engineering (# 89-055); and Technology (#89-065). The reports are available separately or as a set (#89-12X) from: American Association for the Advancement of Science, Department 2061, P.O. Box 753, Waldorf, MD 20604.

CURRICULUM AND EVALUATION STANDARDS FOR SCHOOL MATHEMATICS—This report produced by the National Council of Teachers of Mathematics was designed to establish a broad framework to guide reform in school mathematics in the next decade. Available from: National Council of Teachers of Mathematics, 1906 Association Drive, Reston, VA 22091.

AMERICA'S ACADEMIC FUTURE—This report of the Presidential Young Investigator Colloquium on U.S. engineering, mathematics, and science education for the year 2010 and beyond provides a critical assessment of the status of education in these fields and a vision for the future as seen by the young faculty. NSF Report # 91-150 is available from: National Science Foundation, Washington, DC 20550.

REPORT OF THE UNIVERSITY-WIDE TASK FORCE ON FACULTY REWARDS—This task force was established in 1990 to review academic personnel policy and rewards at the University of California. It advocates the restoration of a more appropriate balance among the traditional categories of scholarly activity of the faculty and the judicious exercise of flexibility in evaluation of faculty performance. Available from: Prof. Karl S. Pister, Department of Civil Engineering, University of California, Berkeley, CA 94720.

THEY'RE NOT DUMB, THEY'RE DIFFERENT—This book by Sheila Tobiasa, a noted political scientist, recounts the results of studies identifying the reasons so many students abandon science for other disciplines. This scathing account of the ineffective methods in common use in the college science classroom is available from: Research Corporation, 6840 East Broadway Boulevard, Tucson, AZ 85710-2815.

SCHOLARSHIP RECONSIDERED: PROPERTIES OF THE PROFESSORIATE by Ernest L. Boyer—This report by the Carnegie Foundation describes the dependence of collegiate instruction on scholarship in a way that recognizes the strengths of U.S. higher education and shows how to use these strengths to improve it. Available from: Princeton University Press, 3175 Princeton Pike, Lawrenceville, NJ 08648.

SCIENCE AND ENGINEERING INDICATORS—This annual report to the President by the National Science Board provides public and private policymakers with a broad base of quantitative information about U.S. science and engineering research and education and about U.S. technology in a global context. Available from: Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

STATEWIDE SYSTEMIC INITIATIVES IN SCIENCE, MATHEMATICS, AND ENGINEERING EDUCATION—Program Solicitation for the Directorate for Science and Engineering Education, Division of Teacher Preparation and Enhancement, Science and Mathematics Education Networks Program (NSF #90-47) is available from: National Science Foundation, Washington, DC 20550.

SCOPE, SEQUENCE, AND COORDINATION—This major reform project by the National Science Teachers Association aims to restructure science education at the secondary level. Emphasis is on a fully integrated approach throughout the junior high and high school years. More information is available from: National Science Teachers Association, 1742 Connecticut Avenue, Washington, DC 20009.

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