Science Education

Introduction

The subject you have asked me to talk about this evening, science education, is one I have been thinking a great deal about recently. Like many of you, I have shared the growing public concern about the overall quality of education in our country.

For example, last week in a special supplement to the Sunday edition of the New York Times entitled "Science Under Scrutiny" a number of alarming facts were noted:

I. In international comparisons, the United States high school seniors ranked l4th among l4 nations in science achievement.

2. College science enrollments have declined by over a factor of two over the last two decades.

3. Of those who enter college intending to major in science, forty percent drop out after their first course and more than sixty percent drop out before graduating with a degree in science.

4. Foreign nationals now comprise sixty percent of engineering and mathematics doctorates and over fifty percent of physical science doctorates.

But I have yet another involvement with this important issue. As a member of the National Science Board, for the past several years I have served on its standing committee on education and human resources. Furthermore, a few years ago I served with one of our colleagues, Professor Homer Neal, on a special subcommittee charged with evaluating the state of undergraduate science education in the United States. Our findings were made public in what is referred to as the Neal Report which concluded that there was overwhelming evidence that undergraduate education in science, mathematics, and engineering was simply not fulfilling its mission.

To quote the report, "Serious problems, especially problems of quality, have developed during the past decade in the infrastructure of college-level education in the United States in mathematics, engineering, and the sciences. That a deterioration of college science, mathematics, and engineering education, this is a grave, long-term national threat."

These concerns also relate to some broader themes, the themes of change that I have placed before this University during the past year:

> l. The changing nature of our population as we become ever more diverse and pluralistic;
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> 2. The changing nature of our ties to other nations and other peoples; and
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> 3. The changing social, cultural, economic, and intellectual activities as we evolve from a resource and labor-intensive society to a knowledge-intensive society.

I have suggested that these changes would demand change as well in the institutions that serve our society, and particularly in higher education. I have even suggested that we should view the l990s as a time to meet the challenge and the opportunity to re-invent the university, to design a university of the 2lst century. In fact, I am convinced that if we do not try to shape our own destiny in the years to come, it will be shaped for us by external forces and interests.

Of course, I don't have the answers about what it will mean to re-invent the university. Quite the contrary! What I have to offer are some questions, observations, and speculations about the issues of renewal and revitalization in our teaching, research and service missions. In this way I hope to begin a dialogue across our campus over the coming year that will engage us all in thinking and discussing the future and our place in it.

On some occasions later this year I plan to say more about these matters, including our relations with other societal institutions, the changing nature of undergraduate education, the role of the liberal arts, and our fundamental missions of research, graduate and professional education, and service.

However, this evening I want to focus my remarks on some questions about intellectual renewal of undergraduate education with a particular focus on a number of issues relating to the manner in which we approach science education, both as preparation for a career in the basic or applied sciences, as well as viewing science as a critical component of liberal learning necessary for life in the 2lst century.

The Age of Knowledge

Let me begin, however, by first pointing to some of the handwriting on the wall; by commenting briefly on the rapidly changing world in which we live and the kind of future for which we must prepare.

Looking back over history, one can identify certain abrupt changes, discontinuities in the nature, the very fabric of our civilization: the Renaissance, the Age of Discovery, the Industrial Revolution.

There are many who contend that our society is once again undergoing such a dramatic shift in fundamental perspective and structure. Today we are evolving rapidly into a new post-industrial, knowledge-based society, just as over a century ago, our agrarian society evolved through the Industrial Revolution. We are experiencing a transition in which intellectual capital, that is brain power, is replacing financial and physical capital as the key to our strength, prosperity, and social well-being. As Erich Bloch, Director of the National Science Foundation, puts it, we have entered a new age, an "age of knowledge in a global economy." And in this age the major forces behind economic and social change are science and technology themselves.

Of course, we know that technology has been transforming our society at an ever accelerating rate. We are living in a time in which the application of knowledge through technology is pervasive in all human affairs. Indeed, technological innovation, achieved by applying new knowledge created through basic research, has been responsible for the dominant part of all U.S. productivity gains since the Second World War. It is clear that the technologies of transportation and communication have made possible the integrated world economy which now characterizes our society. Tremendous new industries have been created by new knowledge. Electronics is the obvious example of the past several decades and perhaps biotechnology will be the example in the years ahead. These and other new industries all depend on knowledge, and the people who create and apply it, as their most critical resource.

But of course, knowledge is highly mobile, it is not tied to geographical regions nor to political structures. The knowledge revolution today is happening world wide, and it is happening very rapidly. The fact that new technology is intimately fueling economic development and trade has become widely understood in all developed nations. They are now sharply increasing their investments in science and technology, research and education. Less developed nations have also learned the lesson and have invested accordingly. Indeed, countries like Brazil, India, Singapore, and Korea are rapidly advancing along the competitive path that Japan took thirty years ago. As more countries understand that knowledge is now the critical resource for economic prosperity, more are making serious investments in their science and technology base. In this sense then, our nation is being challenged in the knowledge business not only by Europe and Asia but increasingly by Latin America and Africa as well. We no longer have a corner on the market. The field is leveling out.

The Challenge of Change

But beyond the changing economic order, today we are also entering a period of great intellectual change and ferment. New ideas and concepts are exploding forth at ever-increasing rates. We have seen that each advance can call into question fundamental premises.

Think about the recent instances in which a new concept has blown apart our traditional views of the field. As we have seen in my own field of physics, the l9th century view of our world gave way to Einstein's theory of relativity and quantum mechanics. Our understanding of the molecular foundations of life is changing dramatically the very nature of the biomedical sciences. Examples abound today of striking new discoveries signaling potential revolutions of similar magnitude in the nature of our scientific knowledge. Disciplinary boundaries are crumbling. Technology is extending the reach of science to the edge of the universe and the beginning of time.

Hence, it is clear that if we are to harness the power of this knowledge explosion for the good of man, the capacity for intellectual change and renewal will be of critical importance to us as individuals and to our institutions. As the pace of creating new knowledge accelerates, we are entering a period in which permanence and stability are less important than flexibility and creativity. This is a period in which the only certainty will be the presence of continual change. And the capacity to relish, stimulate, and manage change will be one of the most important skills we can give our students.

In some ways, so much change and instability is daunting. But we should take heart, because as Alfred North Whitehead said, "The great ages are unstable ages."

Clouds on the Horizon

The Pipeline Problem

The unprecedented explosion of knowledge we are experiencing means that we will be relying increasingly on a well-educated and trained work force to maintain our competitive position in the world, our standard of living at home, and our social stability. Previous economic transformations in America, for example the introduction of modern agriculture and the industrial revolution, were associated with major public investment and infrastructure such as railroads, or electrical networks, or highways. Today the equivalent infrastructure will be an educated population. It seems clear that education will be the pivotal factor in determining the direction of the economic transition in this country and its effect on our citizens.

This being so, we face very serious difficulties ahead because we are simply not educating enough new people to keep our economy competitive.

Further, there are serious signs that the education of the present American workforce is simply inadequate to meet the demands of the next century.

This challenge has become known as the "pipeline problem" since it involves the full spectrum of education, from pre-school through K-l2, through higher education, through graduate and professional education, to lifelong education and to science literacy.

K-l2 Education: A Nation at Risk

Last December I attended a conference of the top scientists, government officials, and corporate leaders from around the world. At this meeting, a senior executive of Nissan reported that after an extended visit to the United States, a number of senior Japanese officials were asked to assess America's greatest strengths and weaknesses. The group unanimously responded that America's greatest strength was its system of higher education, particularly our research universities. Our greatest weakness was considered to be our system of primary and secondary public education.

By any measure, K-l2 education is in serious trouble. We are indeed "a nation at risk". Our educational system simply has not responded to the challenges of the age of knowledge. Despite the current explosion of knowledge, it is clear that both the knowledge and skills of the graduates of our primary and secondary education systems continue to deteriorate. At every level of education American children are ranked near the bottom in their knowledge and skills of academic science and mathematics when compared to peers in other advanced nations.

By any reasonable standard, it is clear that we are in serious trouble. For example, in tests of composition ability, only twenty percent of high school seniors were able to write an adequate letter. Only twelve percent of these students could reorder a group of six fractions by size. Astonishingly, only five percent of high school graduates were entering college ready to begin college-level science and mathematics courses. These and many other measures demonstrate quite forcibly that only fifteen to twenty percent of our children are reaching an intellectual level that will enable them to function in the everyday world, and only five percent will be capable of further education in science when they leave high school, even if they have a desire.

College Education

The good news is that our colleges and universities continue to be the envy of the world. But here, too, we face major challenges. Of particular concern are projected demographic trends.
The dominant factor controlling the supply of scientists and engineers is the size of the college age population. As we slide down the backside of the post-war baby boom, the number of students of college age is declining rapidly. From l976 through the mid-l990s, a twenty to twenty-five percent decline in the number of high school graduates is expected. Assuming that the fraction of these graduates choosing to enter science and engineering stays the same, and assuming constant demand for scientists and engineers (both very conservative assumptions), the

National Science Foundation now estimates that there will be a cumulative shortfall of almost 700,000 scientists and engineers by the turn of the century. To put it another way, just to compensate for the demographic decline, the fraction of students choosing science and engineering majors will have to increase by over forty percent to maintain even the present number of graduates.

But the composition of the college age population is also changing, even as it declines in magnitude. In l966, forty-four percent of college freshmen were women. Today the number is fifty-two percent. In addition, by the turn of the century, roughly one-third of college age students will be people of color. If present trends continue, by the year 2020, thirty percent of college age students will be African Americans and Hispanic Americans, students who have not traditionally had the encouragement or the opportunity to pursue science and engineering careers.

The most striking recognition is that during the l990s, almost ninety percent of the new people entering our labor force will be women, minorities, and immigrants. This means that the fastest growing pool of young adults is comprised of minorities who have traditionally had the lowest participation rate in college, the highest drop-out rate in high school, and the least likelihood to study science and mathematics. In fact, although blacks and Hispanics presently account for twenty percent of our population, they account for less than two percent of our scientists and engineers. Women account for only fifteen percent of scientists and engineers. It seems that that at all the key decision points during a student's career, from K-12 to undergraduate to graduate and professional schools, minorities and women fall away from the science, mathematics and engineering pipeline at a steeper rate than the rest of our population.

There is yet another factor that intensifies concerns about the nation's supply of educated scientists and engineers. For a number of years Kenneth Green and his colleagues at UCLA have been performing longitudinal studies of freshman interest in undergraduate majors. They have found that over the past two decades, freshman interest in undergraduate science majors has declined by almost one-half. The overall proportion of freshmen planning on majoring in mathematics and science has dropped from ll.5 percent to 5.8 percent. More specifically, the proportional change by field is striking:

Mathematics: 4.6% to 0.6%

Physical Sciences: 3.3% to l.5%

Biological Sciences: 3.7% to 3.7% (although over two-thirds of these are pre-med majors)
Engineering: I2% to 8.6% over the past six years
Computer Science: 8.8% to 2.7% over the past six years

In sharp contrast to the dismal losses in the sciences, they found that undergraduate business majors have now increased from I0.5 percent to 23.6 percent.

Perhaps most depressing of all, Green and his colleagues are finding that the earlier patterns that saw prospective secondary school science and mathematics teachers pursuing undergraduate majors in these disciplines, has essentially disappeared. Very few aspiring science and mathematics majors plan careers as high school teachers. In addition, studies have indicated that over one-half of those freshmen selecting science majors either change their minds during entry-level courses, drop out at a later point, or reluctantly complete their programs rather than "waste" investments of time, energy, and money. Students view entry-level courses in science as either inaccessible or unrewarding. It is tragic but many freshmen who have come to science well prepared and expecting to major in science disappear after the freshman year due to their performance or frustration with entry-level courses.

The results at the University of Michigan are quite comparable to those observed in the Green studies. If we track the number of upper class concentrators in science majors over the last twenty years, we find the following changes from I969 to I989:

Mathematics:	28I to I60
Physics:	97 to 6I
Geology:	3I to I3
Biology:	essentially stable
but with 65% indicating pre-med majors	

Further, a recent survey conducted by the Women in Science Program found that of 420 seniors graduating in I987, thirty-five percent of women and twenty-four percent of men initially interested in science later decided against it due to problems with entry-level courses. Of these, eighty-five percent reported that they had taken courses which had discouraged them from continuing the study of science. Even among those who remained in the major, sixty-five percent reported that the courses that they had taken as entry-level courses had seriously discouraged them.

Science Literacy

In our world today we are witnessing an unprecedented explosion of knowledge. Indeed, in some fields the doubling time for new knowledge is roughly five years. In some rapidly evolving engineering fields in fact, graduates find their knowledge almost obsolete by the time they finish their degree program. And yet, in the face of such an extraordinary growth in knowledge, public ignorance is truly extraordinary. A recent NSF survey indicated that only eighteen percent of those asked said that they knew how a telephone works, and when questioned, only one-half of these gave the right answer. Yet, more than one-half of those surveyed indicated that they believed that we were being visited by aliens from outer space. In another test of scientific literacy, it was found that only three percent of high school graduates met the test, twelve percent of college graduates, and only eighteen percent of Ph.D.s! It is clear that most people, including many highly educated people, are not only ignorant of science but many are actually hostile to it. In a sense, we are rapidly becoming a nation of illiterates in science and technology no longer able to comprehend, control, nor cope with the technology that is governing our lives.

The Deemphasis of Science Instruction in Undergraduate Education

Those of us in universities have to accept some responsibility for this frightening situation. Through our undergraduate curriculum, we prepare our graduates to cope with a world of scientific and technological change, compensating in part for the deficiencies of our K-12 education system. Yet, today in American universities we have ceased insisting on a balanced education for our students. We have failed to provide them with the foundation necessary to cope successfully with the increasing pace of scientific and technical change. Amazingly, most colleges require only two or three semesters of courses in science and mathematics for non-science majors, and these are generally watered down courses at that.

It wasn't always this way. Over almost I50 years ago, in I850, Harvard required all of its undergraduates to take twenty-five percent of their curriculum in mathematics and science, including physics, zoology, chemistry, and biology. Indeed, the Harvard curriculum included a course in science or mathematics in every semester of study. By contrast, today for non-science majors, Harvard requires only two one-semester courses; one in the physical sciences and one in the natural sciences. Stanford similarly requires only three one-quarter courses; one in science, one in mathematics, and one in computers (which is essentially a word processing course).

Conclusions

It seems clear that if we look at the combined effects of demographics with student preferences and educational trends in our universities, we have a time bomb on our hands. We are not only educating too few scientists and engineers to sustain the strength and prosperity of our nation, but we are producing a generation of Americans who are scientifically illiterate, and indeed will suffer from a life-long estrangement from the very knowledge that will govern their lives in the years ahead.

Time is running out. We have two major challenges to address: First,

we must plug up the leaks in the education pipeline so that more students manage to make it through the gauntlet by majoring in science and mathematics. Second, over the longer term, it is clear that we must reform the education system, that is, completely rebuild the pipeline to respond to the changing world in which we live.

In our colleges and universities it is time to think about improving what we teach, who we teach, and how we teach.

Some Observations and Questions

Entry-Level Science and Mathematics Instruction

As we have noted, there is an alarming loss of students in the early college years due to difficult courses, bad teaching, and declining interest. Indeed, forty percent of those entering college intending to major in science drop out after entry-level courses. Fully sixty percent will drop out before completing a major. In fact, we see in science courses and science curricula, perhaps the ultimate example of the modern university's focus on the selection rather than the development of human talent; we focus on "weeding out" rather than "adding value." Every year thousands of academically talented and highly motivated students enroll in college with the intent of majoring in science--and then drop out.

A recent survey by the University of Michigan Women in Science program identified a number of the problems students encounter including the poor quality of teaching in introductory courses; the overall classroom attitude; the impact of stereotypical attitudes towards women and minorities among professors, TAs, and fellow students, and the lack of role models in introductory science instruction. But the problems are far deeper than this.

In many universities science departments have developed an almost perverse attitude of taking pride in the number of students who flunk out of introductory science courses. The difficulty of introductory courses in chemistry and physics has been legendary. In fact, organic chemistry is generally regarded as not simply a career shaping, but in fact, a career stopping experience for a great many pre-med students. At times there seems to be an almost informal competition to see which science classes can achieve the lowest grades or lowest mean GPAs, which can eliminate the most students from the field.

Instead of focusing on selectivity in this way, perhaps we should question instead the viability of any program that loses one-half or more of its potential clients. This is particularly questionable because the sciences generally tend to attract a disproportionate number of academically able and motivated students. Kenneth Green observes that "if undergraduate science departments were run like for-profit businesses--that is, without substantial institutional subsidy--most programs would be bankrupt, largely because of their capacity (some say basically inclination) to alienate potential clients."

Perhaps it is time that science departments move away from the perspective of their role as a "talent filter" designed to separate out only the most talented and motivated students, and instead develop a perspective of encouraging students to pursue the sciences. Perhaps deans, chairs, faculty, and particularly students, should be asking hard questions, not simply about the research reputation of a department, but beyond that about its record in student recruitment, defection, and persistence rates. Perhaps we need a fundamental shift in attitude. Why not aim to enable the largest possible number of students to succeed in introductory science courses.

The Quality of Science Teaching

The fact that more than fifty percent of entering freshmen intending to major in the sciences fail to complete the B.S. program in these fields, is a major problem. It is compounded by the number of future teachers, lawyers, politicians, and citizens who are rendered permanently allergic to these fields by unfortunate encounters with introductory courses. Surveys indicate that the majority of students find that introductory level courses, whether geared to majors or to students satisfying general education requirements, fail to educate them about the subject, let alone stimulate and involve students. Students report that the courses are largely irrelevant to their lives and the effort required far exceeds the benefit reaped. Perhaps their view is short-sighted. But there is no arguing with the fact that entry-level courses are not encouraging and enabling large numbers of students to continue further study and careers in science.

There are other more fundamental problems. The higher levels of intellectual abstraction required by modern science has led to an intensification of the introductory curriculum. All too frequently courses demand that students master abstractions before they have developed adequate experience and understanding of the phenomena characterized by the abstractions. Further, introductory science instruction rarely takes into account the differences in intellectual and emotional maturation development of students. Instead, all students are forced to move at the same pace and follow the same method.

The Science Major

The high attrition observed among prospective undergraduate science majors suggests that it may be time to re-think our basic concept of the undergraduate major. Science majors are typically structured as narrow, rigidly sequenced, and intensively hierarchical programs with little flexibility. Students view these programs as superhighways with no interchanges or exits.

Ironically, this narrow approach to science education contrasts sharply with the strong intellectual pressures that are connecting the classical disciplines, mathematics, physics, chemistry, and biology, with the applied sciences, engineering and medicine. If anything, there has been more hardening of the disciplinary arteries with ever increasing specialization, excessive abstraction divorced from context, and a distinct state of disciplinary inertia. Our present department structure itself, characterized by limited communication and coordination, and strong possessiveness for students, may no longer be able to reflect this interdependent nature of the sciences.

Science as a Component of the Liberal Arts

It is clear that mathematics and science instruction has largely disappeared from the general requirements of the undergraduate curriculum. Furthermore, the past century has seen a period of intellectual fragmentation in which the humanist and scientific cultures have drifted further apart. This has happened despite the obvious importance of the natural sciences to a liberal education. Like the arts, the humanities, and social sciences, the natural sciences are an expression of our human culture. To be ignorant or alienated from the sciences is to lose touch with a part of ourselves and our civilization. Especially when science and technology so dominate our lives, how can we afford to leave its development and application to a few "experts." It seems to me imperative that we begin to redesign the liberal arts curriculum to once again include a very substantial mathematics and science component if we want to provide a liberal education appropriate for the 2lst century. There must be an integration, not of the arts and the sciences, but rather the arts with the sciences.

Some General Recommendations

Each generation must face the challenge of determining for itself and for its age what the core of a liberal education should be. In most colleges today there is little faculty consensus about the purposes or appropriate context of an undergraduate education, either in general or in the sciences. An important first step is to bring together the science faculty with their colleagues in the humanities and social sciences to determine the role of the sciences in a liberal education.

I believe both students and faculty have a common interest in trying to reconceptualize and revitalize entry level courses and core sequences. There is a real irony here, since most scientists truly enjoy teaching. Yet, as a result of the present reward structure, few are fortunate enough to be able to devote a significant portion of their time, energy, and creativity to teaching. This can diminish the innovation and creativity that is the key to learning. Can we redesign entry level courses to enlarge the window of entry into the sciences by rewarding our most talented faculty for creative teaching and by rethinking methods, structures, and context?

One of the key problems in introductory science is our continued dependence upon the lecture format. This is probably the least effective way to facilitate learning in the sciences. Studies show that scientific understanding develops best when students become active partners in learning, when they are encouraged to see science in its human context, and when they can refine their interpretations through collaboration with peers and mentors.

It also is essential that the very best faculty be brought into the design and teaching of entry level courses in an effort to convince more students to pursue majors in the sciences. Furthermore, we should rely far more heavily on learning through doing, on understanding the underlying principles and methods of science, and on using hands-on experiences rather than simply encouraging our students to accumulate facts and passively accept the opinion of others. We might also make far more use of novel teaching techniques, such as the use of "peer" teaching assistants (that is, outstanding undergraduates who have recently completed the same course sequence). Furthermore, we have barely begun to exploit the possibilities of new instructional technology that can extend the reach of both students and teachers.

The tightly sequenced majors now characterizing most science disciplines should have more flexibility to allow students the opportunity to both interrelate and perhaps even shift among science majors as their interests change. At the same time, I am convinced we simply must reduce tensions in the science majors which are simply too intense and do not allow adequate opportunity for a liberal education. The undergraduate curriculum should be viewed as a network of roads with many points of entry and many points of crossover.

Students should be able to exercise many more options to broaden their academic programs and shift to other majors. Since the curriculum of most science majors is already seriously overburdened, the exponential increase of new knowledge and skills can only be incorporated by reforming existing content, not by making majors even more intense. But, of course, here we run into a major challenge within the academy because of strong faculty resistance to removing or changing course content, no matter how obsolete or irrelevant.

Both the explosion and the evolution of scientific knowledge demand a life-time commitment to formal learning if professionals are to stay current. This should be built into the re-design of the undergraduate curriculum. At the recent Sigma Xi Conference on Science Education at Wingspread, the participants concluded that, "The fundamental goals of undergraduate science education for all students should be the development of a knowledge base and intellectual skills that enable them to engage in lifelong science learning and to be able to apply their scientific knowledge to personal, professional, and civil endeavors."

More Specific Recommendations

A Science "Liberal Arts" Major

Perhaps as science faculty we need to take a broader view of the science major itself and cease assuming that every student majoring in our field intends to become a professional scientist. After all, most history majors do not intend to become historians; most philosophy majors do not intend to become philosophers. But we assume that all physics majors will become physicists, all chemistry majors will become chemists, and so forth. We hence design highly specialized and intensive majors with this in mind.

What about a physics, or a chemistry, or a mathematics major for students intending to continue their studies in other professions such as business, law, teaching, or politics? Indeed, it seems that a liberal education with a strong concentration in the sciences would be an excellent preparation for the age of knowledge which will characterize our society in the years ahead.

Major/Minor Curriculum Options

In years past it was common to encourage or even require students to pursue intensive studies in both "major" and "minor" areas. For example, the physics major might have a minor in English literature, or the English major might have a minor in astronomy. Perhaps we should once again encourage our best undergraduates to pursue two majors--or at least a major and a minor--in widely separated fields of studies. Should we encourage our best students to become intellectual "straddlers," capable of spanning and hence integrating the interdisciplinary areas of vastly different perspectives? People capable of bridging scientific cultures, social and humanistic fields and concerns will be valued leaders in our future.

The Science Content of the Liberal Arts Curriculum

We are doing great disservice to our undergraduates and to society by allowing them to leave the university scientifically illiterate. The fact is that the natural sciences are a critical part of the liberal arts education demanded by our age. Unfortunately, few of our graduates leave our institutions today with a truly liberal education. Indeed, many of our faculty have not had the opportunity to benefit from a liberal education from this broader perspective.

A century ago it was felt that at least twenty-five percent of the undergraduate curriculum of a liberal education should consist of science and mathematics. Is it not appropriate to question whether in this age that is increasingly dominated by science and technology, a similar content is needed by our students today? In fact, one might note that if "technical" institutions such as MIT and Caltech demand that their science students take at least twenty-five percent of their studies in liberal arts, perhaps liberal arts colleges should require that humanists invest twenty to twenty-five percent of their studies in the sciences, at least leading them up a gentle slope to higher levels of scientific understanding.

Transition Majors

Our present approach to science education is essentially a filtering process, a highly critical and hierarchical sequence of courses which pile, one upon another, thereby making it very difficult for students to change directions as their interests or abilities mature. It is possible to design an educational program--although perhaps using non-traditional instructional methods--at the upper class or graduate level that would allow students with degrees in social sciences or humanities to make the transition into further graduate studies and careers in science. One of the fundamental reasons today for the inability of students to make such lateral educational transitions, is the highly vertical nature of instruction in the sciences. We insist upon building sciences one block of knowledge upon another. We ought to look at other disciplines such as the humanities that are far more horizontal in nature, being primarily extensive rather than intensive. Unlike literature or social science, the highly vertical subjects of science are maintained to be difficult to learn after college; hence, we suggest to students that unless they learn the language of science and mathematics early, they are likely to find science inaccessible later in their education or professional lives. Recent studies of learning suggest that as students acquire more intellectual maturity, the learning process assumes more of a parallel, non-linear nature. True learning consists of mastering a subject simultaneously from a variety of perspectives, rather than proceeding in a sequential fashion to higher and higher levels of understanding. Hence, perhaps we should re-think how to build programs of science instruction for students of greater intellectual maturity, even if their particular background is in sharply differing areas such as humanities or social sciences.

Lifelong Education

Perhaps we should simply conclude that our conventional perspective of science education as a four-year undergraduate major--or even as an eight to ten year graduate program--is obsolete in a world in which the growth of knowledge increases at exponential rates. The explosive increase of scientific knowledge and the uncertainty about what knowledge will be required to comprehend future issues make it impossible for any student to acquire the knowledge in an undergraduate education necessary for a life time. Instead, might we not be better off by considering science education as a life time commitment to formal learning and use the undergraduate experience to prepare our students for this future. Then, if we begin with the assumption that our students would continue to study throughout their professional careers, we could redesign our undergraduate programs to make them far less specialized and far more suited to a world of change.

America at the Crossroads

Today our nation faces serious challenges that will clearly determine its future prosperity and well-being: the challenge of pluralism, the challenge of participation in a global community, the challenge of the age of knowledge, and the challenge of change itself. As we approach a new century, America is undergoing a profound and difficult transition to a new economic and social order. Our prosperous industrial economy, an economy that allowed us to build the world's great institutions, including some of its finest universities, is rapidly disappearing. Our challenge for the decade ahead is to take the steps necessary to build a new knowledged-based society which will be competitive in a world marketplace.

Let there be no mistake about it. This will not be an easy transition. The outcome is still very much in doubt.

It is clear that the ties between the quality of life in this country and the educational skills of our people are strong. It is also clear, unfortunately, that unless there is a revolution in the way we promote learning, the nation's economic standards will follow those of the test scores of our students.

In my frequent interactions with leaders of the public and private sector throughout this nation, I detect an increasing sense of pessimism about our nation's will and capacity to take the actions necessary to prepare for this future. Indeed, many now believe that our nation is well down the road to "outsourcing" its knowledge resources, just as we have been our labor, our manufacturing, and our products. There is an increasing sense that American industry can no longer depend on domestic knowledge resources, that is, upon a well-educated labor force or an adequate supply of scientists, engineers, and other professionals. This arises because of three factors:

l. There is increasing pessimism that the staggering problems facing K-l2 education can be overcome on the timescale necessary to preserve our economic strength.

2. Further, despite the fact that most other nations regard higher education as America's greatest strength, there is little sign that this view is shared either by our elected political leaders or the public at large. Indeed, it has become fashionable to attack our universities, even as we continue to seriously underfund them.

3. The rapid growth of "transnational" companies that seek resources, whether they be labor, processes, or knowledge wherever they can get them--highest quality and lowest priced--suggest that outsourcing of knowledge from other parts of the world will become increasingly common as the quality of American education deteriorates.

This is truly a frightening prospect. Industry has already outsourced labor and manufacturing. Can our nation afford to lose its competitive capacity to produce and apply knowledge as well?

We simply must face the facts. We are not going to be prosperous if all we do is mow one another's lawns -- or worse yet, arrange leveraged-buyouts of each other's companies financed by junk bonds. We have to bring something to the table of the international marketplace. We have to generate our wealth through our people, through their knowledge and their skills.

I, for one at least, do not share the pessimism of many of my colleagues. I believe we can meet the challenge of the knowledge based and global society that is our future. But it is also clear that to do so will require will and sacrifice by us all. It will require renewed commitment to that most fundamental of all characteristics in the new economic order, quality. And it will take renewed investment in that most critical resource for our future, our system of public education.