

Science Education 1.4

Title:

America at the Crossroads:
The Challenge of Science Education

Introduction

Science Education for the 21st Century,

The subject you have asked me to talk about this evening
is one I have been thinking a great deal about recently.

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 Homer Neal
on a special subcommittee to evaluate the state of
undergraduate science education in America,
leading to the so-called Neal Report.

Our concerns here have been both the growing shortfall
in scientists and engineers facing our nation and
alarming lack of scientific literacy among our
populace as we face an increasingly technological
world.

“Science Under Scrutiny” (NYT, 1/7/90)

In international comparisons, US high school
seniors ranked 14th among 14 nations in
science performance.

College science enrollments are at an all-time
low.

Of those who enter college intending to major in science,
40% drop out after first course.
60% drop out by graduation

Foreign nationals now comprise 60% of engineering doctorates,
50% of physical science doctorates
40% of mathematics doctorates

But these concerns play into broader themes,
the themes of change I have placed before this University
over the past year or so...

...the changing nature of our population
...the changing nature of our ties to other
nations and other peoples
...and our 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 bring change
as well to the institutions that serve our society...
and in higher education in particular.

Indeed, I even suggested that we should view the 1990s as
a period in which we have both the challenge and
the opportunity to re-invent the University...
to design a University of the 21st Century.
because I believe that if we do not try to shape our
own future, it will be shaped for us by external forces
and interests.

But I haven't come here this evening with answers about what
all of these means...

Quite the contrary!

What I have to offer are some are questions,
observations and speculations about
the issues of renewal--revitalization--
in our teaching, research and service missions.

In this way I hope to begin a dialog across our campus

that will engage us all in thinking about the future and our place in it. On some occasions later this year , I plan to say more about all of these matters, including our relations with our community, liberalizing the liberal arts, as well as about our fundamental missions of research, graduate and professional education and service. However, this evening, I will focus my remarks on some questions about intellectual renewal of undergraduate education with a particular focus on a number 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 a critical component of the liberal learning necessary for life in the 21st Century.

The Age of Knowledge

Let me begin, however, by first reading some of the handwriting on the wall...by commenting briefly on the rapidly changing world in which we live, and the kind of future we must prepare for. 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 to a new post-industrial, knowledge-based society, just as a century ago our agrarian society evolved through the Industrial Revolution. A transition in which.. Intellectual capital--brainpower-- is replacing financial and physical capital as key to our strength, prosperity, and well-being This is having a profound impact on our social structure, culture, and economy. 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 in recent years. Whitehead has said that "Great ages are unstable ages." And I think we are living in a dazzling time. It is a time when the application of knowledge--technology--are pervasive in human affairs. Technological innovation, achieved by applying new knowledge created through basic research, has been responsible for nearly half of all US productivity gains since WWII At another level, technologies of transportation and communication make possible an integrated economy. Tremendous new industries have been created by new technical knowledge: electronics is the obvious example of the last three decades; biotechnology may be the example for the coming three decades. These industries depend on knowledge as the most critical resource. But knowledge is highly mobile...it is not tied to

geographic regions as coal or iron or oil.

By contrast, the knowledge revolution is happening worldwide and at a very rapid rate.

That new technology means economic development and trade is widely understood in developed nations who have been sharply increasing their investments in science and technology.

But less developed nations are also learning the lesson and drawing knowledge from the developed world or generating it themselves.

Brazil, India, Korea are quickly advancing along the competitive path that Japan took 30 years before.

Example:

Over past two decades, India has increased its population of scientists and engineers by tenfold!!!

Note: As more countries understand that knowledge is now the critical resource, more are undertaking serious research programs. Our nation is already being challenged in the knowledge business itself, not only in Europe and Asia, but increasingly in Latin America and Africa as well.

We do not have a corner on the market. The field is leveling out.

The Challenge of Change

Today we have entered a period of great intellectual change and ferment...

New ideas and concepts are exploding forth at ever increasing rates...

We have ceased to accept that there is any coherent or unique core of wisdom that serves as the basis for new knowledge...

We've seen simply too many instances in which a new concept has blown apart our traditional views of a field...

Einstein's theory of relativity
quantum mechanics
the molecular foundations of life...
superstring theory

We are increasingly surrounded by radical critiques of fundamental premises and scholarship...

Hence the capacity for intellectual change and renewal has become increasingly important to us as individuals...and to our institutions

As the pace of the creation of new knowledge accelerates, it seems apparent that we are entering a period in which permanence and stability become less valued than flexibility and creativity...

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 abilities of all for the students we educate.

Clouds on the Horizon

The "Pipeline Problem"

Today, an unprecedented explosion of knowledge heralds the onset of a new era. Since people are the source of new knowledge, we will rely increasingly on a well-educated and trained work force to maintain our competitive position in the world and our standard of living at home -- and indeed to harness the power of this new knowledge for the good of our planet and all of mankind.

Central theme is that education, broadly defined, will play a pivotal role in the coming economic transition and its impact on individuals.

Previous economic transformations were closely associated with major public investment in infrastructure such as railroads, canals, electric networks, and highways. In the coming economic transition, an equivalent infrastructure will be an educated population.

Yet here we are in real difficulty, because we are 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.

Key input to a competitive economy is quality of the workforce. Our principal competitors are simply producing workers better capable of absorbing modern production skills.

This has become known as the "pipeline problem", since it involves the full spectrum of education, from preschool through K-12 through higher education to lifelong education and science literacy

Discuss Pipeline Graph of NSF

Furthermore, the dropout rate is extraordinary...

From 8th grade through PhD, the half-life of students in the mathematics curriculum is one year! That is, if we begin with 32 million students in junior high school, we lose 50% each year until only a few hundred attain the PhD.

K-12 Education: A Nation at Risk

In December I attended a conference of the top scientists, government officials, and CEOs from a number of nations throughout the world. The CEO of Nissan pointed out that following an extended visit by a number of senior Japanese officials, they asked the group what they felt the greatest strength and weakness of the US were: The greatest strength was felt to be our research universities. Our greatest weakness was felt to be public education at the primary and secondary level.

By any measure, K-12 is in serious trouble.

We are "A Nation At Risk"...

Our education system simply has not responded to the challenges of the age of knowledge...

Yet, in the face of this knowledge explosion, 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 rank near the bottom in their knowledge of science and mathematics when compared to peers in other advanced nations.

Even if we don't include the dropouts, we are only educating 15% to 20% of the kids to an intellectual level capable of functioning well in the everyday world --only 20% could write an adequate letter.

Only 12% of 17 year olds could tax six fractions and put them in order of size.

The high point is represented by those who can really enter college ready to begin college-level math/science or reading of technical material. Here, only 5% of high school graduates are up to snuff.

Our students bring up the rear in most international comparisons

College Education

While our colleges and universities are the envy of the world, here

too we face major challenges.

Demographic Factors

Dominant factor controlling BS degree supply is the size of the college-age population, which will decline until the late 1990s

Traditional source of S&E college students is declining
25%-30% falloff in HS graduates by 1992

Assuming that same fraction (4.8%) choose to enter S&E, and assuming constant demand (very conservative), drop will be from 197,000 (83) to 152,000 in 1996; there will be a cumulative shortfall of 675,000 by 2000!

To put it another way, fraction of students choosing S&E majors will have to increase by 40% to maintain even present level of graduates.

Composition of college age population is also changing...

In 1966 44% of college freshmen were women; today 52%.

By 2020 30% will be composed of Blacks and hispanics...

students who have not traditionally chosen S&E careers.

Indeed, by the turn of the century, over 50% of K-12 students will be Black or Hispanic.

Less than 15% of new people entering the labor force of the 1990s will be white males.

The fastest growing pool of youths has the lowest participation rate in college and the highest dropout rate in high schools -- not the mention the least likelihood to study science and math.

Indeed, while Blacks and Hispanics account for 20% of total population, they account for less than 2% of scientists and engineers!

Blacks: 2.5% of engineers and scientists

Hispanics: 2% of all scientists and engineers

Women: 15% of all S&E

At all the key decision points during a student's career, blacks, hispanics, and women fall away from the sciences, math, and engineering at a steeper rate than the rest of the population.

We must reverse this now, because women and minorities are the key human resource of our future.

Interest in Science and Engineering Majors

ACE-UCLA Cooperative Institutional Research Program (CIRP) survey of entering college freshmen (Kenneth Green)

Freshman interest in undergraduate science majors has dropped dramatically--by almost half--over the past 23 years.

Freshman interest in technology careers has also dropped over in past 6 years--engineering falling by 25%, computers falling by 75%.

Over past 20 years, proportion of college freshmen planning on majoring in BPM has dropped from 11.5% to 5.8%.

Mathematics: 4.6% to 0.6%

Physical Sciences: 3.3% to 1.5%

Biological Sciences: 3.7% to 3.7%

(but most of these are premed)

Engineering: 12% to 8.6% over past 6 years

Computers: 8.8% to 2.7% over past 6 years

Women: 8.8% to 5.1%

Where have the students gone?

Business: 10.5% to 23.6%

The disciplinary-training of secondary school science teachers has declined dramatically over the past two decades. Today very few aspiring science and

math majors plan to pursue careers as high school teachers.

A high proportion of freshmen who enter college planning to major in these fields either change their minds during entry-level courses, drop out later, or reluctantly complete their programs rather than “waste” the investments of time, energy, and money.

Summary: Longitudinal studies of freshmen preferences indicate that a tremendous number of aspiring science majors ultimately “defect” to other non-science fields. Indeed, the sciences have the highest deflection rates and lowest “recruitment” rates of any undergraduate fields.

Attrition Among Undergraduate Science Majors

One problem has to do with our priorities.

While many scientists like to teach, relatively few have the good fortune to be able to devote a significant portion of their time, energy, and creativity to excellence in teaching without accepting significant professional and monetary penalties.

Students view entry-level courses in science as inaccessible or if accessible, unrewarding to them. Many freshmen who come to college well prepared and expecting to major in science disappear after the freshman year even though they may have done very well in AP courses. Entry level courses are “watersheds” that determine both the place of science in the lives of those who go to college and the vitality of UG programs in science.

Common practice of using entry-level courses as barriers to protect more advanced courses for all except the most able students still persists, and at worst, students view these classroom environments as destructive and hostile. A positive and supportive human environment has value to all students and is particularly valuable to women and minorities. The success of many liberal arts colleges in encouraging and enabling undergraduates to pursue graduate student in science and mathematics may lie in a rich human support system made available to their students.

Indeed, the general response to the quality of science education from educators has been “Don’t educate them better; raise the standards, filter harder. We’ve gotten so good at weeding out that no one’s left.”

The higher levels of intellectual abstraction in modern science has led to intensifying the introductory curriculum, asking students to assimilate abstractions before they have sufficient experience with the phenomena that are the rational base of the abstractions, and in so doing, making SME inaccessible to many students.

There is strong evidence that students learn best from hands on activities with peers, not from lectures or rote acquisition of facts.

So too, the reliance of research universities on teaching assistants who all too frequently lack the motivation, preparation, or communication skills to teach well strikes another blow at the quality of UG instruction.

UM Science UG Majors

Compare 1965 to 1985 (20 years)

Math: 290 to 111 (62%--factor of 3)

Physics: 71 to 38 (factor of 2)

Chemistry: 142 to 151 (stable)

Geology: 22 to 21 (stable)

Compare 1970 to 1990 (20 years)

Math: 281 to 160 (-43%--factor of 2)

Physics: 97 to 61 (-33%)

Geology: 31 to 13 (factor of 3)

Biology: 65% are premed

CEW Women in Science Study

Based on 420 seniors graduating in 1987

Among those who were initially interested in science,
35% of women and 24% of men did not decide to major

Of these, 85% reported that they had taken courses
which discouraged them from pursuing the study
of science

Even among those who stayed in the major,
65% reported having taken courses that
discouraged them (43% the first year)

Negative experiences:

How courses were taught.

Overall classroom atmosphere

Presence of stereotypical attitudes toward women
among professors, TAs, and fellow students

Lack of female models in science

Lack of knowledge about possible scientific careers

Concerns about combining career and family
roles and responsibilities

Scientific Literacy

We really haven't appreciated impact of technology.

Today we are witnessing an unprecedented explosion of
knowledge.

Technology doubles every 5 years in some fields!

Graduates are obsolete by the time they graduate!

Technological change is a permanent feature of our environment

Examples of just the past few months:

i) hole in the ozone layer over Antarctica

ii) new supernova in the heavens

iii) new high temperature superconductor

iv) a new theory suggesting that all matter is composed
of infinitesimal "superstrings" rather than point particles

Yet, at the same time public ignorance is extraordinary!

A recent NSF survey indicated that only 18% of those
asked said they knew how a telephone works -- and
only half of these gave the right answer.

Yet more than half of those surveyed indicated they
believed we were being visited by aliens from outer
space!

By surveys, very low levels of scientific literacy...

3% of high school graduates

12% of college graduates

18% of PhDs

It is clear that most people--including many intelligent people--
are not only ignorant of science, but many are actually
hostile to it.

We are rapidly becoming a nation of illiterates ...

in science and technology, no longer able to comprehend
or cope with the technology that is governing our lives.

Public's knowledge and understanding of science has not

kept pace with technology

The Deemphasis of Science Instruction in Undergraduate Education
We have to accept some responsibility for this frightening situation.

"Literacy" in science and technology will increasingly become a requirement for meaningful participation in life of the 21st Century.

All Western thought for past 300 years has been firmly grounded in results of scientific revolution that began with Copernicus, and Newton and evolved through Einstein and Heisenberg.

Any university that graduates students who are not at least conversant in

Yet in American universities we do not insist on a balanced education for our students--with providing a background necessary for coping with the increasing pace of scientific and technical knowledge that will be so critical to participating fully in a future of change.

Yet, most colleges shy away from even attempting to provide a complete education. Indeed, most require only 2 or three semester courses in science--and these are generally watered down courses at that.

It wasn't always this way. In 1850 Harvard required 25% mathematics and science including physics, zoology, chemistry, and biology--indeed, the curriculum included a course in science or mathematics--or both--in every semester of study.

Today, for nonscience majors:

Harvard: two one-semester courses, one in physical sciences, one in natural sciences

Stanford:

One quarter course in science,

One quarter course in math

One quarter course in computers (word -processing)

Harva

We are abdicating our responsibility to our students and our society when we do not address the issue directly.

What does an educated person need to know to function in an age of knowledge.

As scientists, we have a special responsibility to struggle with this question and to reach out to our faculty colleagues across the university to engage in intensive dialog leading to action.

By not addressing this issue in our universities, we may be condemning an entire generation of college graduates to a lifelong estrangement from the very knowledge that may govern their lives in the years ahead.

But, even beyond that, we may have abdicated our commitment to providing a liberal education to our students.

Note that the liberal arts include the natural and social sciences.

Together the natural and social sciences and humanities are known as the liberal arts because of their potential to liberate the human intellect and the human spirit.

From this perspective, it is clear that few students today are receiving a truly liberal education!!!

NSB Report:

Evidence mounts that UG education in science, mathematics, and engineering is not fulfilling its mission.

"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."

"The deterioration of college science, mathematics, and engineering education is a grave, long-term national threat."

Conclusions:

- i) If we couple demographics with student preferences, we have got a timebomb on our hands...
- ii) Indirect effects, since smaller enrollments in S&E will mean less justification for investments in faculty and facilities...
- iii) We must act rapidly...
First to plug up the leaks in the pipeline...
Then, over the longer term, to reform the education system in American to respond to a changing population and a changing world.

Some Observations and Questions

Entry Level Science and Mathematics Instruction

There is an alarming loss of students in the early college years due to difficult courses, bad teaching, and declining interest.

40% of those intending to major in science drop out after first course

60% drop out before completing major

In fact, science courses and curricula are perhaps the ultimate example of the modern university's focus on human talent selection rather than development--

...the focus on "weeding out"
...rather than "adding value".

Each year tens of thousands of academically-able and well-motivated students enter college planning to study science--and drop out. There is a tremendous talent loss that institutions and programs need not incur.

In short, science departments lose a huge proportion of their potential "clients" or customers--academically-able and intellectually motivated students who enter college with a genuine interest in studying science.

Actually, on many campuses science departments often take great pride in the number of students who "flunk out" of key courses in the lower-division sequence or who ultimately change majors. This has long been a hallmark of the sciences: certainly organic chemistry has been a traumatic if not a career-shaping--or career-stopping-- experience for pre-med students. Yet there also seems to be almost an informal competition to see which science classes have the lowest grades or which programs have the lowest mean GPAs.

Any organization or enterprise that loses half or more of its potential clients is in trouble. And these data should be especially troubling given that the sciences attract a disproportionate number of academically-able freshmen.

"If undergraduate science departments were run like for-profit business--that is, without substantial institutional subsidy--most programs would be bankrupt, largely because of their capacity (some might say basic inclination) to "alienate" potential clients." (Kenneth Green)

Perhaps science departments should move away from a perspective of their role as a "talent filter", designed to separate out only the most talented and motivated students, and instead develop an environment that encourages students to pursue the sciences, an

environment that is perceived as encouraging success rather than has hostile and designed for failure.

Deans, chairs, and faculty and students should be asking hard questions fundamental questions

...not simply about the level of research activities

...but about recruitment, defection, and persistence rates among aspiring science students.

...about who we teach, how we teach, and what we teach.

Perhaps what is needed is a shift in attitude in which we attempt to enable the largest possible number of students to succeed!

The Quality of Science Teaching

More than 50% of freshmen intending to major in SME fail to complete the BS program in these fields, to say nothing of the many future teachers, lawyers, politicians, and citizens who are rendered permanently allergic to these fields by unfortunate experiences in introductory courses.

Why do over half of those intending on majoring in science drop out?

UM Women in Science Survey:

Poor quality of science instruction

Classroom atmosphere

Presence of stereotypical attitudes toward women among faculty, TAs, and fellow students

Absence of effective role models

To many entry level courses, whether geared to majors or to students satisfying general education requirements, fail to stimulate and involve students--much less educate them.

Students complain that the courses are largely irrelevant to their lives and that the effort required far exceeds the benefit reaped.

It is clear that entry-level courses are not sufficiently rewarding to encourage and enable large numbers of students to pursue careers in SME.

The higher levels of intellectual abstraction required by modern science has led to intensifying the introductory curriculum, asking students to assimilate abstractions before they have sufficient experience with the phenomena that are the rational basis for the abstractions, and in so doing, making science and mathematics instruction inaccessible to many students.

Further, science instruction rarely takes account of the sharp differences in intellectual (and emotional) maturation rates of students. Rather all students are generally forced to move at the same pace.

The Science Major

Do we need to rethink our basic concept of the science major?

Science majors are generally structured as narrow, tightly sequenced, and intensive hierarchical programs with little flexibility. Students view these as "superhighways with no interchanges or exits"...

How relevant is our present disciplinary approach to the undergraduate science major?

There are strong intellectual pressures blending together the classical disciplines--mathematics, physics, chemistry, biology--and indeed, even some blending with the applied sciences (engineering, medicine).

Yet, if anything, there has been further "hardening of the disciplinary arteries" with

...every-increasing specialization
...excessive abstraction, divorced from context
...disciplinary inertia

The departmental structure characterized by limited communication and coordination, department possessiveness for students, are not conducive to the interdependent nature of the sciences.

Pressures forcing convergence of basic and applied sciences...

Time-scale of research, development, implementation

Cross-disciplinary nature of important problems

Moving from "natural science" to an age in which science may be less concerned with nature, and more concerned with man-made objects

Biological molecules

Synthesized organic molecules

Integrated circuits

Artificial retinas

Computers

Other manifestations of our knowledge and ingenuity

Federal Trends: emphasis on macro, systems

NSF-NSB: ERCs, "big engineering" like "big physics"

Pushing engineering toward private sector?

Pushing engineering away from single-investigator activities toward cross-disciplinary team research

Bankruptcy of traditional ABET curriculum

Importance of liberal education

Intellectual Questions:

Engineering \Leftrightarrow Applied Science \Leftrightarrow Basic Science

Science \rightarrow Engineering \rightarrow Systems \rightarrow Society

Scientific foundation \rightarrow Subsystems \rightarrow Systems

Macro vs. Micro

But A.N. Whitehead warned in his Essay on the Aims of Education

"We must beware of what I will call inert ideas, that is to say, ideas that are merely received into the mind

without being utilized or tested or thrown into fresh combinations

."Every intellectual revolution which has stirred humanity into greatness has been a passionate protest against inert ideas. Then, alas, it has proceeded to bind humanity afresh with inert ideas of its own fashion."

Science as a Component of a Liberal Education

Science Literacy:

It is clear that undergraduate science courses and curricula influence the scientific literacy of all Americans-- either directly or through the training of teachers.

Yet, not only has mathematics and science instruction largely disappeared from the undergraduate curriculum, but the last century has seen a period of intellectual fragmentation in which the humanist and scientific cultures have drifted farther apart.

It is clear that we need to redesign the liberal arts curriculum to once again include a very substantial mathematics and science component in our effort to achieve a "liberal education" appropriate for the 21st Century.

There must be an integration not of the arts AND the sciences, but rather the arts WITH the sciences.

Because the truth is that literary, artistic, and scientific cultures are expression of one common human culture.

Last century has seen a period of intellectual fragmentation in which the literary and scientific cultures have drifted farther apart.

Few can now claim to be broadly educated

across the arts and sciences.

What needs to be affirmed and encouraged now is the reunification of the liberal arts core, even within the reality of an explosive expansion in knowledge.

Some General Recommendations

1. In most colleges, there is not a faculty consensus on the purposes of undergraduate education, whether in general or in the sciences. Hence the first task is to bring together science faculty with their colleagues in the humanities and social sciences to determine the role of the sciences in a liberal education.

2. It is clear that entry level courses and core course sequences need to be rethought (if not entirely replaced) from the perspectives of the students as well as the faculty.

While scientists like to teach, relatively few have the good fortune to be allowed to devote a significant portion of their time, energy, and creativity to excellence in teaching without accepting significant professional and monetary penalties.

There is far too little innovation and creativity that attempt to take advantage of how learning really occurs.

No wonder our students leave our disciplines.

Indeed, it is amazing that any persevere!

How can we re-design entry level courses to enlarge entry window, taking into account differing maturation rates.

Studies show that scientific understanding develops best when students are active partners in learning through interacting with the physical world and refine their interpretations through social interactions with their peers and mentors.

When courses depend exclusively on lecture and reading to transmit the canons of science, students do not come to understand that the methods of science are as important as the body of knowledge that the methods develop.

Because students are unaware of the broader applications of scientific knowledge and skills, they do not value science.

- J. Bronowski in his Science and Human Values puts it this way.

“It is a common and cardinal error to suppose, as the nineteenth century supposed, that the facts on which science builds are given to us absolutely and call for no judgements or interpretations from us.

The great discoveries in the physical sciences in the twentieth century begin from a radical denial of this philosophy.

We now understand that science is built not on facts but on observations; that observation is not a passive state of reception, but an active relation between the observer and his world; and that science therefore is not a mechanical index of facts, but an evolving activity.”

3. It is essential that the very best faculty be brought into the entry level courses in an effort to convince more students to pursue majors in the sciences.

We are not presenting the excitement of learning.

It is ironic that at a time of such dazzling advances, in knowledge, our teaching methods have hardly

changed at all.

4. Where possible, one should move away from the lecture format and stress instead laboratory and field experiences and team learning activities.

One should move away from large lecture formats as the dominant method of instruction--

Some recent research on the effect of public speakers on an audience...

...the audience is able to pay attention and remember most of what a speaker says for the first 10 minutes

...for the next 10 minutes, their minds begin to wander

...then, after 20 minutes, the majority of people in any audience begins to have sexual fantasies

"So at least I want you to know that you will enjoy a part of my speech."

These courses should be concerned with the processes of investigation and hands-on experience, not simply accumulating facts and passively accepting the opinions of others.

Perhaps far more use should be made of

...“peer” teaching assistants...i.e., undergraduates

...as well as instructional technology (e.g., Mathematica)

...Kleinsmith’s successes in biology--

5. The tightly sequenced majors now characterizing most science disciplines should be made more flexible, allowing students the opportunity to both interrelate and perhaps even shift among science majors as their interests shift.

Must reduce tensions in science majors which are simply too intense--and do not allow enough opportunity for a liberal education.

Many problems with tightly sequenced majors, since these are seen as one-way roads by students.

UG curricula should be viewed as a network of roads with many points of entry and many cross overs--points of opportunity to broaden academic programs and move to other majors.

6. Since the curriculum of most science majors is already seriously overburdened, the exponential increase of new knowledge and skills can only be accommodated by replacing existing content, not by making majors even more intense.

7. Indeed, both the explosion and evolution of scientific knowledge demand a lifetime commitment to learning, and this should be factored into the design of the undergraduate curriculum.

Faculty should develop courses and programs that effectively integrate the practical and liberal aspects of education in the sciences.

Consequences of neglecting the liberal aspects of education in the sciences tend to make students less valuable and adaptive in the workplace.

For example, if science faculty view the purpose of preparation of concentrators solely as vocational training--the development of the technical skills and knowledge required for a life in research--there is a danger that the social and ethical issues that confront practicing scientists will not be examined as part of UG experience.

Saxon: “a liberal education should give all students a sense of the richness and complexity of creativity

in the humanities (and in life--sac) and an understanding of how that kind of creativity concerns itself not so much with the measurable and quantifiable aspects of the world as with the universals of human experience. A liberal education should help all students understand how the humanities seek to explore not only the rational but the other dimensions in our experience that are no less real and no less significant than those revealed by science."

8. 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.

UG courses and curricula in sciences influence the scientific literacy of all Americans--either directly or indirectly through teachers.

Although academic scientists have the potential to influence scientific literacy, their attention has been largely directed toward building the nation's science research capability.

Faculties have the essential task of preparing UGs for life in a society in which science is becoming more pervasive; at the same time, they must also maintain or improve the education available for students intent upon careers in science.

Let me digress for a moment to suggest that as scientists we need to be concerned about educating the broader public, not just our own students.

I think we need to try to communicate what we do and why it is important, and to be involved in the reforms of K-12 education as well as undergraduate and professional education.

We are an arrogant lot, on the whole--and a privileged one.

I think we can repay society for granting us the privilege to teach and do research by actively contributing to public understanding of the strengths of science and its limitations.

More Specific Recommendations

1. 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..or philosophy majors philosophers... (some may even become investment bankers!!!)

Yet we assume that all physics majors will become physicists, all chemistry majors will become chemists...and so forth...and hence design highly specialized, intensive majors with this in mind.

What about a physics, chemistry, or mathematics major for students intending to continue their studies in other professions such as business, law, or medicine?

Indeed, it would seem that a liberal education with a strong concentration in the sciences would be an excellent preparation for the "age of knowledge" characterizing our society in the years ahead.

2. 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 study.

Study Group concluded that in-depth quantitative understanding of a single natural science is preferable to a superficial survey of several natural sciences--but also that such in-depth knowledge of two or more natural sciences is preferable to knowledge of a single one.

Our ideal can never again be the One Man who individual incorporates all human capacity and knowing, as in the ideal of Jefferson's time-- but perhaps instead the person who works deeply and productively in 2 or 3 disciplines which are not contiguous--in English literature and physics, or in mathematics or art.

Some examples of the Great Straddlers:

da Vinci: military engineer, physician, artists

Darwin: Malthesian economic theory & biological change

Wiener: mathematics, thermodynamics, communication

Prigogine: chemistry, literature, philosophy

Of course, these are towering intellectual figures.

BUt it is possible that we have set our sights too low.

We might be wise to aspire to greater breadth as scholars and teachers.

Why only 2 or 3 fields?

Learning that many disciplines deeply and well is about all that is humanly possible

Further, the object should not be just breadth in the old sense--rather it should be the unpredictable release of intellectual energy which occurs by connecting within one mind two widely separated fields of thought.

Alternative: Case-Western Reserve approach

56 credit hour core in calculus, probability, discrete math (computers), physics and astronomy, natural philosophy, and computer science.

3. The Science Content of a Liberal Arts Curriculum

It is clear that we are doing great disservice to our undergraduates by allowing them to leave the university in a state of scientific illiteracy.

Further, to the degree that the natural sciences are indeed important components of the liberal arts, few of our graduates leave our institutions with a truly liberal education. (Indeed, few of our faculty have benefited from a liberal education from this perspective.)

A century ago it was felt that at least 25% of the curriculum of a liberal education should consist of science and mathematics. Is it not appropriate to question whether in this increasingly science and technology-dominated age, a similar content is needed by our students today.

What can be done? If MIT and Caltech demand that their science students take 25% in the humanities, perhaps we should require that humanists invest 20% to 25% of their effort in science...at least leading them up a gentle slope to a more considerable level of learning.

4. Transition Majors

Our present approach to science education is essentially a

filtering process--a highly vertical 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.

However, perhaps it is possible to design an educational program (although perhaps using nontraditional instructional methods) at the upperclass or graduate level that would allow students with degrees in the social sciences or humanities to make the transition into further studies in science.

One of the fundamental reasons for this difficulty is that education in science is highly vertical, where one subject is built upon knowledge of another, whereas scholarship in the humanities is much less vertical; it is primarily extensive rather than intensive.

Unlike literature or social science, the highly vertical subjects of science are very difficult to learn after college. Unless one learns the language of science, mathematics, in college, one is likely to remain scientifically illiterate for life.

5. Lifelong Education

Perhaps we should simply conclude that our conventional perspective of science education as a four-year undergraduate major--or even as a 8-10 year graduate program--is obsolete in a world in which the growth of knowledge increases at exponential rates.

The exponential increase of scientific knowledge and uncertainty about what scientific knowledge will be required to comprehend future issues make it impossible for any student to acquire all knowledge required for a lifetime anyway.

Of all applications skills, those that contribute to the capacity for lifelong learning are of most basic value.

Instead we might consider science education as a lifetime commitment to formal learning--and prepare our students for this future.

Then if we began with the assumption that our students would continue to study throughout their professional careers, we could probably 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

the challenge of change itself...

As we approach a new century, America is undergoing a profound and difficult transition to a new economic order...

Our fabulously prosperous industrial economy... an economy that allowed us to build some of the world's great institutions---including some of its finest universities--

But that economy is rapidly disappearing...
...and our challenge for the next decade is to take the steps necessary to build a new knowledge-based economy which will be competitive in a world marketplace.

Let there be no mistake about it...this will not be

an easy transition...and the outcome is still very much in doubt.

The ties between the quality of life in this country and the educational skills of our labor force are strong.

Unless there is a revolution in the way we teach and the way we help students learn, it is obvious that the nation's economic standards will follow those of the test scores and the number of majors in math and physical science.

In my frequent interactions with the leaders of the public and private sectors throughout this nation I detect an increasing sense of fatalism about our nation's will and capacity to take the actions necessary for our future.

Indeed, many now believe that that our nation is well down the road toward "outsourcing" its knowledge resources--just as we have been our labor, our manufacturing, our products--since American industry can not only depend on domestic knowledge resources--that is, a well-educated labor force or an adequate supply of scientists, engineers, and other professionals.

- i) There is increasing pessimism that the staggering problems facing K-12 education can be overcome on the time necessary to preserve our economic strength.
- ii) Further, despite the fact that most other nations regard higher education as our 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 attract our universities, even as we continue to seriously underfund them.
- iii) The rapid growth of "transnational" companies which seek resources, whether they be labor, processes, or knowledge--wherever they can get them at highest quality and lowest price--suggests that outsourcing of knowledge from other parts of the world will become increasingly common as the quality of American education deteriorates.

Motorola has set up a permanent recruiting office in India

This is truly a frightening prospect. Industry has already outsourced labor and manufacturing.

Can our nation afford to lose its competitive capacity to produce knowledge as well?

Let's face the facts, people...

We're not going to be rich and prosperous if all we do is mow one another's lawns.

We have to bring something to the table of the international marketplace.

We have to generate our wealth...through our people...their knowledge and their skills.

Even today the US is being temporarily sustained by \$700 B of foreign debt, 50% of engineers as foreign talent...

I, for one, do not share the pessimism of many of

my colleagues.
I believe that we can meet the challenge of the knowledge-based, global society that is our future.
But it is also clear that to do so will require sacrifices on all of our parts...
It will take 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.

Undergraduate Engineering Education

Since I've been taking potshots at everything else, let me aim a few at my own discipline for a moment...

Changes in Engineering Education:

1. We all know the rapidly changing environment in which the engineer must work.
The time scales of research, development, and implementation have been significantly compressed in recent years.
Important problems command far more of a cross-disciplinary approach.
In both the federal and corporate sector, there is an increasing emphasis on the macroscopic, on systems.
2. Indeed, even the tools used by engineers are changing rapidly.
The computer serves now not only as a lever for the mind, greatly enhancing one's intellectual span, but it has also become a medium of communication and collaboration.
While it is clear that one must saturate the engineering curriculum with information technology to take advantage of its enhanced productivity, there are other more profound changes triggered by this tool.
In a sense, the computer is rapidly changing engineering practice because of the degree to which it has extended the intellectual span of the engineer.
It is no longer necessary to pass a product along a sequence of engineers from R&D to design to analysis to production.
Now modern computer-aided engineering tools allow one engineer to span all activities.
Hence engineering practice is increasingly demanding the generalists rather than the specialists produced by our engineering schools.
Furthermore, the computer has provided powerful analytic tools thereby freeing the engineer from the need to spend most of his or her time analyzing a particular design.
Instead the engineering today can explore many designs and let the computer rapidly perform the analysis.
In a sense, the computer now allows us the freedom to reemphasize creativity over analysis.
3. The third theme of change has to do with the use of engineers themselves.
Increasingly, the problem-solving orientation of engineering education is viewed as an excellent "preprofessional" education for a host of other careers, including business, law, and medicine.

Indeed, at Michigan we now find that over 50% of our engineering graduates will find themselves in management positions within five years of graduation.

It is appropriate to ask whether the present, narrowly focused education typical of most engineering programs is really appropriate for the rapidly changing world society in which our students must function.

In the past, engineering education has gone through several identifiable stages of evolution.

Of course, centuries ago, engineering was essentially an art, a craft; and it was passed on from generation to generation by an apprenticeship process similar to that of artisans and craftsmen.

The early 20th century saw the formation of engineering schools, similar to those characterizing other professions such as medicine, which taught the profession in a highly self-contained way.

With the dramatic shift to a scientific base in the years following WW II, we began to see a shift more toward engineering science.

The increased complexity of engineering practice demanded increasing specialization; the four early engineering disciplines--civil, mechanical, electrical, and chemical--have subdivided into dozens of specialties.

Furthermore, engineering functions themselves have subdivided into research, development, design, production, management, marketing, and so forth.

Yet today further changes seem necessary.

The problem is that we really aren't preparing our graduates for a world of change.

In this type of world, the most successful people will be those who can critically analyze ideas, who can look at things from many perspectives.

Yet, in engineering education, we continue to move to more and more specialization.

Furthermore, we are approaching the point of information overload, and it will take highly discerning individuals to figure out what is important, what they should use, and how they can understand it.

Further, too many people coming out of our universities today have weak communication skills and a very limited view of the world.

Young people are too quickly encouraged into job-oriented specialization.

That may have worked for our past industrial and domestic economy, even if it deprived people of a truly rich and liberal education. But today it is simply fool hardy!

Instead, they should use their college education to challenge the ideas of the past, discovering the wisdom of others, exploring knowledge, and stretching the intellectual breadth of their minds.

In the 21st Century people will finally think in terms of life-long education; college will be viewed as only one intermediate step in one's education.

It seems clear that the challenges and changes characterizing our society suggest that the principal focus of an undergraduate education--engineering or otherwise--appropriate for the 21st century will be the goal of liberal learning, that is, a liberal education as the preparation for a lifetime of learning.

Perhaps Emerson put it best in his famous address at Harvard almost exactly 150 years ago:
"College have their indispensable office, to teach elements. But they can only serve us when they aim not to drill but to create; when they gather from far every ray of various genius to their hospitable halls, and by their concentrated fires, set the hearts of their youth aflame."

And of course, that must be our real purpose, to ignite the intellectual fires within each of our students. To stimulate in each of them a spirit of liberal learning that will be with them for the rest of their lives.

I suspect that we have just begun to realize the major changes required in engineering education. I furthermore believe that those changes will be just as profound as the earlier transitions from a craft to a profession or from an "experienced-based" to a "science-based" discipline.

Of course it is true that few today seem to realize the changes which must occur. Industry, government, even present-day engineers, seem satisfied with our present approach to engineering education. Indeed, these institutions even resist changes.

It is natural to fear and resist change. But as scientists, who have helped to bring about so much change, we must be willing to do what is necessary to prepare our students to face a world of change, challenge, and opportunity.

Engineering Education for 21st Century

Common agreement that what is needed is:

Engineers who are technically competent,
socially aware, with a business perspective,
effective communication skills, and
a global awareness.

Yet it is also clear that industry will only support
a 4-year education program (even with inadequate
high school preparation).

("Leonardo de Vinci with a hard hat")

Only solution: must develop an effective lifelong learning
infrastructure.

Two Cultures

Then I think our efforts to reflect on what education
is appropriate for the future must center on

- (1) How to educate about science and technology in broadest sense
both educate scientists
and educate other intellectual leaders
as well as the general public.
- (2) How to renew liberal learning to make it a dynamic force for good
by illuminating the eternal questions and issues of human
and planetary life
"specifically, the study of the humanities
should help science students understand
the limits of rationalism as well as its powers,
even as they learn the enormous difficulty
of making judgements when it comes to
questions of values, although the very process
of living inevitably forces us to do so."

It is no longer possible to consider any person literate
who does not have some knowledge of science.

Conversely, we cannot consider scientist or engineer,
professional or citizen educated unless
they have learned something about human civilization and values

Can we bridge the gap dividing the "two cultures"?

Perhaps the first step is to remind ourselves

that both art and science are products of human culture .
Separation that has occurred has occurred
as an outgrowth of philosophical methods
and propositions and does not reflect any
underlying reality which, of course, is a seamless whole.

Whitehead "But the ideal of the good life,
which is civilization--the ideal of a university--
is the discovery, the understanding, and
the exposition of the possible harmony of diverse things,
involving and exciting every mode of human experience.
Thus it is the peculiar function of a university to be
an agent of unification.Even methods are limitations.
The difficulty is to find a method for the transcendence
of methods. The living spirit of a university could exhibit
some approach to this transcendence of limits."

Saxon

First, we should teach our students that science
is neither a mystery for the few nor a haphazard
collection of facts; that on the contrary,
it is a highly unified and consistent view of the world.

Second, we should describe and explain just
what that view is and in so doing we should seek
to give our students the understanding
that science is built on a foundation of
large general laws that link together various

This brings me to my final and most important point.

The importance of human values and ideals in the education we
provide scientists and non-scientists alike.

Sakharov quote:

We simply must renew our intellectual roots in the values of human
civilization, humane values and civic values.

For our real aim in education is to gain wisdom...

Whitehead:

Role of Research University

US research university is real strength of the country...
and it has had remarkable impact on US.

The real reason for strong federal support of
research was for national defense--and it has
worked incredibly well, giving US strongest
military force in history.

About the only time research university has been
diverted to other purposes was the Apollo
program...and again it worked very well.

Real question: can higher ed can be redirected
toward the new priority of economic
competitiveness? This is a very recent mission...
and it is far too early to tell.

Are there some lessons to learn here?

A civilian DARPA? (John Glenn)

NDEA --> NEEA