America at the Crossroads:

The Challenge of Science Education

Office of the President

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"Science Under Scrutiny" (NYT, 1/7/90)

- **US seniors rank 14th out of 14 nations in science testing.**
- **College enrollments in science majors are at an all-time low.**
- **Of entering college students intending to major in science,**
  40% drop out after first course...
  60% drop out before graduating...
- **Foreign nationals now earn 60% of engineering, 50% of physical science, and 40% of mathematics doctorates in US.**

NSB Report on Undergraduate Science, Mathematics, and Engineering Education (1986)

("The Neal 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."

"The deterioration of collegiate science, mathematics, and engineering education is a grave long-term threat to the nation's scientific and technical capacity, its industrial and economic competitiveness, and the strength of its national defense."

Followup to the Neal Report

NSF Activities:

- **Major increase in UG S&E program funding**
- **Workshops, programs, visibility**

Other Efforts:

- **Sigma Xi Workshop (Wingspread)**
- **AAAS Report on "Science and the Liberal Arts"**
- **Activities within the professional societies**

But still a very long ways to go...

The Pipeline Problem

- **K-12 Education**
- **Undergraduate Education**
- **Graduate Education**
- **Lifetime Education**
- **Science Literacy**

K-12 Education: A Nation at Risk

- **10% of Americans are illiterate**
- **25% fail to complete high school**
- **Only 20% of high school seniors can draft an adequate letter.**
- **Only 12% of high school seniors can take a group of six fractions and put them in order.**
- **Only 7% of high school graduates are prepared to take college-level mathematics and science courses.**

Conclusion: We are presently educating only 15% to 20% of our K-12 students to an intellectual level capable of functioning well in the everyday world--and only 5% to a level capable of further studies in science.

International Comparisons

IEA Testing of US students in grades 4, 8, 12:

8th of 17 for 4th graders
14th of 17 for 8th graders
13th of 17 for 12th graders

Math testing: US high school seniors scored in bottom 25% in calculus and algebra achievement tests

College: Demographic Factors

Major factor controlling BS degree supply is size of college-age population.

Demographic decline in number of 18 year olds will continue until mid-1990s, resulting in a 20% falloff from 1975 to 1995.

Assuming that there is no change in the fraction choosing to major in science and engineering (4.8%), projecting a cumulative shortfall of 675,000 B.S. degrees by year 2000.

But must remember changing nature of population:

- **Over 90% of new entrants to labor force in 1990s will be women, minorities, or immigrants.**
- **By 2000, one-third or college age students will be people of color.**
- **While Blacks and Hispanics account for 20% of total population today, they represent only 2% of scientists and engineers.**

Freshman Interest in Science Majors

"Freshman interest in undergraduate science, mathematics, and engineering majors has dropped dramatically over the past two decades" (ACE-UCLA Study--Kenneth Green)

Mathematics:	**4.6% ---> 0.6%**
Physical Sciences:	**3.3% ---> 1.5%**
Biological Sciences:	**3.7% ---> 3.7% (mostly pre-meds)**
Engineering:	**12% ---> 8.6% (over past 6 years)**
Computers:	**8.8% ---> 2.7% (over past 6 years)**

(Where are they now going?

Business:	**10.5% ---> 23.6%)**

Attrition Among Undergraduate Science Majors

"A high proportion of freshmen who enter college planning to major in science, mathematics, or engineering 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."

40% of prospective science majors drop out during entry level

60% of prospect science majors fail to make it to B.S.

Science Literacy

NSF Survey:

Only 18% of those questioned said they knew how a telephone worked...and only half of these gave the right answer.

Yet more than 50% indicated their belief that we were being visited by aliens from outer space...

Surveys of scientific literacy:

3% of high school graduates

12% of college graduates

18% of PhDs

Deemphasis of Science Education in College

General Science and Mathematics Requirements:

Harvard, 1850:

25% of all courses in mathematics, physics, chemistry, biology, and zoology
Typically one science or mathematics course each term

Harvard, 1990:

Two one-semester courses: physical and natural science

Stanford, 1990:

Three one-quarter courses: math, science, and "computers"

Michigan, 1990:

A Liberal Education???

It seems clear that our universities are not providing our students with the education necessary for coping with a world increasingly dominated by science and technology.

But, even beyond that, we have abdicated our responsibility to provide our students with a "liberal education".

After all, together the "liberal arts" include the humanities, the social sciences *and the natural sciences* because of their potential to liberate the human intellect and the human spirit.

From this perspective, it is clear that few of our graduates have received either a liberal education, or an education capable of preparing them for an age of knowledge.

Some Observations and Questions

- **Entry-level science and mathematics instruction**
- **The quality of science teaching**
- **The science majors**
- **Science as a component of a liberal education**

Entry Level Science Instruction

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

In fact, science courses and curricula are perhaps the ultimate example of the modern university's focus on the *selection* rather than the *development* of academic talent...a focus on "weeding out" rather than "adding value"...

Every 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 occur.

Is Entry-Level Science Instruction "Bankrupt"?

In short, science departments lose over 50% of their potential "customers"--academically-able and intellectually motivated students who enter college with a genuine interest in studying science.

Indeed, on many campuses, science departments often take great pride in achieving high attritution rates and low GPAs in introductory courses. Introductory physics and chemistry have long been career-shaping--indeed, career-stopping--experiences.

"If undergraduate science programs were run like a '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 customers." (Kenneth Green)

Do we need a completely different attitude toward entry-level science instruction?

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

Perhaps deans, chairs, faculty, *and students* would be asking hard questions and evaluating programs based on recruitment, defection, and persistence rates among aspiring science students.

Perhaps what is needed is entry level instruction designed to enable the largest possible numbe of students to succeed!

What is wrong with undergraduate science instruction?

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 students, science courses, whether geared to majors or general requirments, fail to stimulate and involve--much less educate--and render them permanently "allergic" to science.

Problems with attitudes toward science instruction

Common practice of using entry-level courses as barriers to protect more advanced courses for all except the most able students.

In this way, entry-level courses become "watersheds" that determine both the place of science inthe lives of those who go on to college and the vitality of undergraduate programs in science.

This approach creates a destructive and hostile environment in entry level courses which is particularly discouraging to women and minorities.

Problems with the content of science instruction

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 sufficienc 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.

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

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Science majors are generally structured as narrow, tightly sequenced, and intensive hierarchical programs with little flexibility. Students view these as "super highways 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

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

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

Science Literacy: Science as a Component of a Liberal Arts Curriculum

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 been an integration not of the arts AND the sciences, but rather the arts WITH the sciences.

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.**

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.**

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

Some General Recommendations (cont)

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 mature.**

6. **Since the curriculum of most majors is already 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.**

8. **The fumdamental 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

1. **"Science Liberal Arts" Majors**
2. **Major/Minor Curriculum Options**
3. **The Science Content of a Liberal Education**
4. **Transition Majors**
5. **Lifelong Learning**

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 philosphy majors philosophers...

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 students 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 is common to achieve 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 two majors--or at least a major and a minor--in widely separated fields of study.

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 scientifically illiterate.

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 eduation. (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 curruculum of a liberal education should consist of science and mathematics. It is not appropriate to question whether, in this increasingly science and technology-dominated age, that a similar content is needed by our students today?

4. Transition Majors

Our present approach to science education is essentially as 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 the sciences.

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.

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.

A Final Warning

Knowledge outsourcing...

Or can we get rich mowing each other's lawns...