Yale Engineering and Applied Science Talk

Title:

Science and Engineering Education in the 1990s and Beyond: The Challenge of Change in An Age of Knowledge

Outline

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2. **Science and Engineering Education: Clouds on the Horizon**
3. **Intellectual Challenges**
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Introduction

Yale Engineering in the 1960s...

When I think back to my undergraduate experience at Yale, almost 25 years ago, I remember an exciting time...

Man was preparing to travel to the moon...

The first integrated circuit had just appeared, triggering microelectronics, computers, and the information age...

And an earlier Yale administration had struck a blow for the liberal arts by taking the last step to demolish the old Sheffiend Scientific School and with it Yale Engineering by converting the School into a Department of Engineering and Applied Science...

Indeed, my class of 1964 was the last to receive the B.Eng degree...

Needless to say, engineering students at that time were a bit concerned...in fact, many of us almost transferred to other institutions.

Yet, ties to the Old Blue held us fast in the end...

Today, it is with some interest that I note Yale's efforts

in recent years to reestablish its science and engineering programs as key priorities...

(I should also note more than an historical interest here, since my daughter will complete a Yale B.S. degree in Molecular Biophysics and Biochemistry next month...)

It seems appropriate to make some

observations from afar about the nature of science and engineering education at Yale...

As an alumnus, to be sure...

As a former dean of engineering...

But, perhaps even more, as a member of the

National Science Board...
and to place Yale's new commitments to science and
engineering within a broader perspective.

The Challenge of Change

My central thesis is that Yale will face a period of not only major responsibility and challenge as it rebuilds in the sciences, but it will also face a period of extraordinary opportunity.

Today, we find a heightened interest in science and technology driven by an important new force--
the challenge of dramatic economic change...

Our traditional industry economy is shifting to a new, knowledge-based economy just as our industrial enterprise evolved
from an agrarian society at the turn of the century.

A transition is occurring in which..
intellectual capital is replacing
financial and physical capital as key to economic development

Some examples:
- Industrial production is steadily switching away from material- and labor-intensive products and processes to knowledge intensive processes:
  - In a car, 40% materials, 25% labor...
  - In a chip, 1% materials, 10% labor, 70% knowledge!!!
- Increasing manufacturing production has come to mean decreasing blue collar employment!
  - In the 1920s, 1 of 3 was a blue-collar worker
  - today 1 in 6 and dropping fast
  - probably to about 1 in 10 by the end of the century...
  - Indeed, UM economic studies suggest that less than 5% of General Motors' work force will be unskilled labor by the year 2000.

In all developed countries, "knowledge" workers have already become the center of gravity of the labor force.

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 force behind economic change is technology, itself.

Of course, we know that technology has played an increasingly important role for many years.
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.

The handwriting is on the wall...

Maintaining America's competitive edge requires attention to our traditional strength -- people and research -- and a strong offensive strategy based on these resources.

Science and Engineering Education: The Clouds on the Horizon

WARNING SIGN 1: America's S&E lead is slipping

No question that US has lost lead in many areas

- Industrial productivity and heavy manufacturing
  - Steel, durable goods, ...
- Energy
- Electronics

Also serious signs that lead is slipping rapidly in

Computers
Aerospace

Moreover, key activities such as product design, engineering, and software development increasingly are likely to be done overseas.

Whether automobiles or refrigerators, computes or microchips, nuclear power or energy transmission systems, the likehood is increasing that the systems are assembled from components designed, engineered, manufactured, and shipped from all parts of the world.

Increasingly, excellence in research and engineering is to be found throughout the world, and the level of innovation is rising abroad. More than 43% of US patents went to foreign entities.

WARNING SIGN 2: We are seriously underinvesting in R&D and **Education**

For over two decades, US investment in civilian R&D has dropped while that of our competitor nations has risen rapidly. US investment in civilian R&D as a percent of GNP is now less than that of any other developed nation.

Almost all growth has gone into military research (70% of federal R&D budget)

Support of basic research has dropped significantly (as has support of research in C&S)

WARNING SIGN 3: The S&E Pipeline Problem

Today, an unprecedented explosion of knowledge marks 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 forced to maintain our competitive position in the world and our standard of living at home.

Yet the US faces a S&E manpower crisis of unprecedented proportions

0. Indeed, today the United States awards the smallest proportion
 of university degrees in science and engineering of any industrialized nation!
1. Proportion of graduating seniors who major in science and engineering is smaller today that it was in 1970s (5%). Particularly severe drops in physical sciences and mathematics. (Fallen by 40% over past decade)

2. Per capita production of US engineers lowest among industrialized nations:
   US: 72,000 (3%) (7 in 1,000 graduates)
   Japan: 85,000 (21%) (40 in 1,000 graduates)
   USSR: 300,000 (35%)
      Japan has doubled its technical workforce in past decade...
         7 of 1,000 American students receive engineering degrees
         40 of 1,000 Japanese -- indeed, Japan with less than half
         the population is producing far more scientists and engineers!
   President of Sony:
      "In US you produce 4 lawyers for every engineer.
      In Japan, we graduate 4 engineers for every lawyer!"
3. More than 60% of engineering PhDs are now foreign
   Indeed, foreign students account for nearly 85% of growth.
   It is bad policy to be dependent on an unpredictable resource
   and not to be able to meet more of our needs with American tealent.

But things are going to get MUCH rougher: NSF Study

1. Demand for S&E likely to go up
   Population is growing
   S&E share of workforce is growing
   Industry is becoming more scientific
   Most experts predict growth in S&E jobs
2. Supply will probably fall off dramatically simply due to demographics...
   Number of 22 year olds is a major driving force in determining BS S&E degrees
   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 930,000 by 2010!
      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.

3. Trends in Intended Majors:

But this situation may become even worse:

Over period from 1966 to 1987, proportion of students who intended to major in physicsal sciences yas dropped from 3% to 1.3%; in mathematics, the decline was from 4% to less than 1%.

Recent trends in engineering also show softening. Applications to most engineering schools are down by 10-20% this year. (USC 30%)

Interest in computer science is always waning. Drop from 4% in 1983 to below 2% in 1987.

Note: dramatic increase in proportion of freshmen interested in business majors--now up to 25% and rising rapidly

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.

4. Compositionof 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.

Furthermore, virtually none of the Black college freshmen who score highest on the SAT intend to major in mathematics or the physical sciences

Among engineering students, 70% complete school... but completion rate among Blacks is 30%; Hispanics 40%.

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

NOTE: We must make special efforts to expand participation by these groups...not just because that is good social policy, but because we cannot afford to waste
their talents!

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 adapt the education system in American to a changing population

WARNING SIGN 4: Undergraduate S&E Education

NSB 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 NSB concludes that the NSF must become a strong leader of a nation-wide effort to enhance the quality of UGS&E education, an effort that will require participation by public and private bodies at all levels."

Engineering Education

At the UG level, concern is primarily one of quality rather than quantity.

Extraordinary quality of students attracted to engineerng has masked the decline in the quality of instructional programs.

Few academic institutions have taken steps to re-establish a balance between engineering enrollments and resources
through major internal reallocation or limits and reductions of
enrollments.

While American industry has been a driving force in the intense
demand for engineering graduates, it has been slow to accept

a corresponding responsibility for supporting engineering at
a level adequate to meet this demand.

Finally, federal programs have tended to focus on K-12 and graduate
level education and research, largely ignoring the fact that
the critical limiting factors in the supply of engineering graduates
are at the UG level.

Industry did the same by focusing support on graduate education
and research that was more closely related to corporate interests.

Nature of the crisis:

1. Faculty shortages
   - 2,000 vacant faculty positions...
   - 50% foreign national
   - Things are only going to get worse...
     - greying of engineering faculty...
     - return of foreign nationals...
     - demographics coupled with declining student preferences...
2. Facilities
   - Few schools have managed to maintain either the quantity
     - or quality of facilities necessary to respond to surging
     - enrollments and sophisticated technology
   - Absence of federal programs to assist in construction
3. Instructional Laboratory Equipment
   - Deterioration in lab equipment is a national scandal
   - NSF surveys indicate that only 16% is state-of-the-art
   - Backlog exceeds $4 billion...
   - Similar investment in computing environment...
4. Curriculum
   - Growing vocational focus of engineering curriculum as more and more specialization occurs
   - Inadequate exposure to engineering practice--particularly

in areas such as design, synthesis, and systems integration

Inadequate exposure to practicing engineers due to research

focus and limited industrial experience of faculty

Traditional approach to instruction along discipline line is

unable to keep pace with intellectual evolution of engineering

practice which tends to be cross-disciplinary in nature

General concern that entry degree should be M.S. degree

Haddad Report:

"Today's four-year baccalaurate engineering curriculum is

largely obsolete. It does not provide adequate depth in

engineering subjects, adequate breadth in engineering

science and mathematics, or adequate exposre to

engineering practice. Furthermore, the largely vocational

focus of most undergraduate programs deprives today's

student, characterized by broader interests and career

objectives than in the past, of the liberal education so

necessary to adapt to technological change and assume

leadership roles in our society."

NSF Study Groups:

"The NSF program should be designed to deliver a good

2x4 shot across the buttocks of engineering education..."

"NSF's role should be to encourage and support the intellectual

efforet necessary to restructure the curriculum and teaching

methods in the light of present day and near future

technical realities. This should be a process of "bottom-up"

rather than "top-down" direction of a program from the
federal level."

NSF Response to Date:

NSB Report recommend +$42 M in FY88 and +$92 M in FY89
targeted across a variety of programs in curriculum development,
laboratory instrumentation, faculty development, and so on.

Yet, in the aftermath of the December deficit reduction actions:
+$8 M in FY88
+$18 M in FY89 (although this is still at risk)

Hence, despite the rhetoric from the NSF, we still have a very
long ways to go...

WARNING SIGN 5: PhD Education: our Future Faculty

of 10,000 HS sophomores, fewer than 20 receive PhD's

Hence US PhDs will decline due to reduced BS graduates

Foreign PhDs are beginning to return...

US universities are becoming less attractive...
we've become complacent

Like balance of trade problem--we are building our
infrastructure (including faculty) on foreign nationals

All multinational companies are going after US-trained
foreign nationals to be based in their home countries

PhD shortage in faculty...

Compensation (in constant dollars) was constant from 1964 to 1984

It has gone up by 21% in past 5 years and will accelerate even
more rapidly as the real PhD shortages appear late in the 1990s

WARNING SIGN 6: Technological Illiteracy

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 mater 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 survyed indicated they believed we were being visited by aliens from outer space!
- And yet, our education system has not responded...
    - Note: it is bad enough that...
        - 10% of Americans are illiterate
        - 25% now fail to complete high school
    - Scientific Literacy of K-12 Teaching Force
        - Only 30% have had college chemistry
        - Only 20% have had college physics
        - Less than 50% have had calculus or computers
    - International Association for Evaluation of Educational Achievement (IEA)
        - Grades 4, 8, and 12
        - US was 8th of 17 for 4th graders
        - US was 14th of 17 for 8th graders
        - US was 11-13 of 17 for 12th graders
        - Bottom 25% of US students were scoring at chance level, indicating that they were scientifically illiterate
        - (Top scores were Japan, Korea, Hungary
        - "For a technologically advanced country, it would appear that a reexamination of how science is presented and studied is required...in the United States."
    - More than half of all our high school graduates have not had even one year of science.
    - Face it, gang:
        - The tragedy is not simply our poor showing relative to other nations.
        - Science, mathematics, and computer literacy will increasingly

        become a requirement for almost all employment.
    We are condemning an entire generation to a lifelong
        estrangement from the very technology that will
        inevitably govern their lives.

Some observations:

- Claim: 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
- If, in the final analysis progress depends on
    - having the generations who follow us be smarter
    - and better educated than we are, it
    - is evident that we are sliding backwards rapidly!

Intellectual Challenges

1. Intellectual Change

1. 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 manifestitations 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 <=> Applied Science <=> Basic Science
        - Science -> Engineering -> Systems -> Society
        - Scientific foundation -> Subsystems -> Systems
        - Macro vs. Micro

2. The Engineering Curriculum

Evolution of Engineering Education

- Stage 1: Artisans and craftsmen -- apprenticeship
- Stage 2: Engineering schools (like medicine) -- teach profession (self-contained)
- Stage 3: Shift to science base -- fundamental science education
  - Complexity demanded increasing specialization
    - • Civil, mechanical, electrical, chemical have subdivided...
    - • Furthermore, engineering functions have subdivided: research, development, design production, project,...
- Yet, despite the increasing emphasis on science and specialization, the engineering profession remains the only profession requiring only a 4-year UG degree!

Factors suggesting a change is needed:

- i) the technology itself
- ii) societal uses of engineers
- iii) quality of students

Technology

- Computer is a "lever" for the mind
  - Now improves both the productivity and the intellectual span of S&E
  - CAD,CAM,CIM, CEP, CAE
- Implications
  - Obvious
    - i) Must integrate ("saturate) curriclum with use of computer
    - ii) Take advantage of enhanced productivity
    - iii) Unleash student's creativity
  - Not so obvious, but more profound
    - i) Computer has changed engineering practice
      - No longer design-analysis-production-...
      - Now one engineer spans...
      - Hence we demand a generalist--not a specialist
    - ii) Computer has provided powerful analytic tools
      - No longer does engineer pick a design and spend days analyzing it
      - Instead, can explore many designs...let computer do the dog work
      - Reemphasizes creativity over analysis--

science back to art
Right to left side of the brain...
NOTE: See Appendix A for a "Case Study" of how
we have responded to this challenge at Michigan
Rapid Pace of Technological Change
Engineers must factor change into their
career objectives
Change is a permanent feature of our environment
Continuing education will be an absolute necessity
Societal Uses of Engineer:
Why do students choose engineering?
i) Excitement about science and engineering?
...or money $$$
ii) As a "preprofessional" education (problem
solving--analytical)
We now find students spring off engineering
into other professions
Business (30% of MBAs), law, medicine, academe
At Michigan, 50% of graduates will be in
management
with 5 years
Question:
Is our present, narrowly focussed education appropriate
for the future leaders of America?
Importance of a broad and liberal education
Not just technical subjects, but art, literature, history...
Note: With this broadening, an engineering education
will be far more "liberal" than other fields which do
not include science and technology
Importance of generalist approach
Maybe a general undergraduate education followed
by graduate studies
How do we reintroduce creativity into education?
Can we "teach" creativity?
Suspicion
We have just begun to realize major changes required in
engineering education.
These changes will be just as prfound as the earlier
transitions from a craft to a profession or from an
"experience-based" to a "science-based" discipline.
Major frustration:

Few seem to realize the changes which must occur
Industry, government, present-day engineers seem satisfied
Indeed, they even resist such changes
Perhaps it will be the extraordinarily talented students now seeking engineering education who will demand the changes.

Science and Engineering Education at Yale

An Obvious Conclusion

Yale faces unusual responsiibilities, challenges, and opportunities...

Responsibilities

I would contend that Yale has a responsibility to this nation
to make the sustained commitment
to build outstanding programs in science and engineering...
But it also has a responsibility to itself...
Indeed, I believe that no modern university can be distinguished without a major commitment to both basic and applied science...

Challenges

because of the rapid changes taking place in science
and engineering education and practice

Opportunities

because of the increasing importance of the research university in a knowledge intensive society

Question: But what should the "flavor" of E&S be at Yale?

Can spot a number of models...
MIT/Michigan/Berkeley/Cornell
"mega-engineering"...
E.g. At Michigan, EECS has 1,800 students...
We graduate 1,700 engineers each year!
Yale cannot do this...at least without seriously
distorting the institution
The Harvard Style...
Engineering at Harvard = MIT
(Where can Yale find an analog in New Haven?...)
Let me suggest an alternative...in fact, another one of my alma maters...
The Caltech model:
Strong focus at the interface between engineering and basic science
The Caltech style...

Do only what you can do very well...
Focus your resources on a few areas in which you can really be leaders...
Build "spires of excellence", to use an old Fred Terman phrase...
Try to work on the early, exponential portion of the "Knowledge Curve", where a few individuals of unusual talent and broad intellectual span can have extraordinary impact.

Yale cannot be an MIT or Michigan...but, if it focuses its efforts, and choses these areas with "good taste" to be at the cutting edge, it can play a leadership role for far larger engineering schools.

The Opportunity for Leadership

Yale aspires to leadership in education and scholarship.
It is therefore natural to expect the same aspirations to apply in engineering and applied science!

Yale is positioned to develop the new paradigms for the interaction between the basic and applied sciences.

The extraordinary quality of your students and faculty...and the reputation of the University--will allow you as well to play a leadership role in developing a new concept of the liberal education in which literacy in science and technology is pursued with the same vigor as literacy in culture, the arts, and the humanities.

And, of course, since Yale is one of the key sources of the leadership of this nation, you have an unusual opportunity to produce leadership as well in science and engineering in the years ahead...

I believe that you have taken important steps in this direction in recent years...and I, and many other alumni, will be watching with both interest and pride as you continue to accelerate your pace in the years ahead.

Appendix: A Case Study: Michigan's Information Technology Effort

UM Engineering

Some of us were convinced that the computer would rapidly involve from simply a tool for scientific computation or information processing into an information technology infrastructure absolutely essential to all of our activities...from research to instruction to administration

I was also convinced that to build a leading Engineering college, it would be necessary to become a leader in information technology.

As with all such efforts to achieve leadership, the key lay with people...in attracting to Ann Arbor individuals with unusual vision concerning the impact this technology would have on engineering education and practice.

With these people pushing hard, we set a rather ambitious goal: To build the most sophisticated information technology environment of any Engineering college in the nation...an environment that would continually push the limits of what could be delivered in terms of power, ease of use, and reliability to our students, faculty, and staff.

Goals:

i) To provide an environment where computing resources were as accessible and used as naturally as mathematics

ii) To provide state-of-the-art computing facilities, equivalent to equipment and software used in the high technology industries who seek our graduates

iii) Service concurrently and comprehensively all dimensions of engineering computing needs: research, instruction, and administration

iv) Provide resouces for a broad range of science and engineering disciplines

v) Develop a hierarchical structure of networks involving multiple communication protocols, sup0porting workstations of greatly differing power and characteristics, and providing complete nodal interconnection and extensibility

CAEN:

The Computer Aided Engineering Network

Sophisticated information technology network integrating the College's instruction, research, and administrative activities together with both oncampus users (students, faculty, staff) and off campus participants (industry, government)

CAEN was a distributed intelligence, hierarchical
computing system linking personal computer workstations, superminicomputers (and, more recently, minisupercomputers) mainframe computers, function specific machines (CAD, simulation, AIA) and gateway machines to national networks.

The network was designed to support non only general
scientific computing, but computer aided instruction, administration services and provide access to technical and bibliographical databases.

It was also designed to be a test bed for R&D in computer and communication engineering.

First steps:

1. Provided very faculty member with workstation
2. Built large clusters of state-of-the-art workstations for students (Apple Lisas, IBM, Apollos, Suns, Silicon Graphics, ...what's NeXT...)
3. Networking...
4. Servers...
   - MOSIS
   - Flexible manufacturing cells
   - Supercomputers (Alliant, Hypercubes, NSF centers...)
5. Corporate relationships
   - DEC
   - Apollo
   - Sun
   - AT&T
   - Apple
   - "Jobs-Poduska" announcement
   - "Jobs-Scully" interaction

Today

- Workstations
  - 350 top-end workstations (Apollos , Suns, MicroVaxes...)
  - Well over 1,000 Macs, PCs, ...
- Clusters
  - Roughly 20 to 30, ranging from large facilities with a hundred or so workstations, to small local facilities with a dozen or so machines at the department level
- Servers
  - Alliant minisupercomputers
  - Harris UNIX servers

Sun fileservers
Networking
Ethernet
Appletalk
Domain rings
Proteon Fiberoptic Ring
Some measures:
Storage: 50 gigabytes on the network servers alone...
(not counting workstations themselves)
Roughly 100 times the processing power of MTS
20 full-time staff...100s of students
Philosophy
i) Determined to stay always at the cutting edge...
but with very strong service focus
ii) Determined to remove all constraints...no limits
whatsoever on student and faculty use...
iii) Multivendor environment
iv) Move with whatever technology was the most
powerful...e.g., CAEN is based on a UNIX kernel...
MTS is really only used as a communication channel

University Level

Early 1980s...
Also apparent that the University could benefit from a
similar commitment...
Hence, many of us pushed very hard to achieve a
major University commitment to regain its leadership
in information technology...and, indeed, to use this
as an important component in building the
distinction of the University...
Initial Efforts
i) Student access program
Computer fee $150 per term ($9 M per year total)
Initially 1500 workstations
ii) Networking
Northern Telecom wireplant
iii) Mainframe
IBM connection
iv) Supercomputer Center
Fujitsu...
(shooting ourselves in the foot...)
Structures...

- CITI
  - Center for Information Technology Integration
- CMI
  - Center for Machine Intelligence
  - Cognitive Science and Machine Intelligence Lab
- EXPRES
- NSFnet (IBM, MCI)
  - NSF Supercomputer centers
  - NASA, Internet,...
- MITN

Today...

- i) roughly 2400 public student workstations
  - (including exciting programs like RESCOMP)
- ii) roughly 20,000 workstations
- iii) world networking center...
  - Last year 25% of Telenet through UM
- iv) access to supercomputers throughout
  - the nation (SDSC and PSC charter members)

Tomorrow...

- Personal computing to "interpersonal computing"
  - As the result of the rapid spread of personal computers and computer networks, and the development of new insights into human cognition and group behavior, we are at the threshold of a major shift in the underlying paradigms and uses of information technology.
  - The shift will be from solo use of personal computers to group use of collaboration technology.
- Group process underpin all human activity and work.
  - Past research in computing technology has focused on the solo user.
  - But groups activities such as brainstorming, planning, and making decisions in group settings will require new technology.
- Center for Collaborative Science and Technology
  - UM, MIT, PARC
  - Organization theory, cognitive psychology, anthropology, human-computer interaction, artificial intelligence, and multi-media information technology