DESIGNING NEW PRINCIPLES TO SUSTAIN RESEARCH IN OUR UNIVERSITIES

(An Open Letter to CS&E Faculty)

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Dear Colleagues,

The system of university research in which we have staked much of our careers and our reputations is at risk. It faces curtailment at many institutions and extinction at some.

Across the land, university faculty have been experiencing angst, confusion, and uncertainty about the continuing stasis of budget, salary, faculty, and staff size and about continuing growth in student count and workload. When will this end, we all ask? Will it pass when the recession passes? Will the recession end? Will President Clinton make things better?

In the background is a mass of complaints by students, parents, business executives, and public officials about our enterprise. The complaints feature the charges that we professors are deserting the undergraduate classroom in order to pursue research, that we do not really care about our undergraduate students, that our curricula are too theory-oriented, and that we are raising tuition much faster than the value of the education we are providing. The complaints lead to radical proposals such as requiring faculty to be in the classroom 12 hours weekly and even banning research from the campus. No matter that these complaints may hold us all guilty for the abuses of a few: they are part of the public psyche anyway. These complaints reflect a widespread dissatisfaction with education in general that has spread to higher education: they do not result from a deterioration of our enterprise, but from a massive shift in the public expectation of what our enterprise is supposed to do.

It is easy to ignore public moods and go about the daily business of education and research. But like it or not this mood is now affecting our daily working lives and our careers. Our professionalism is attacked in highly visible, best-selling books including *ProfScam* (1988), *Impostors in the Temple* (1992), and *How Professors Play the Cat Guarding the Cream* (1992). The financial resources to enable us to do our job are being cut. Virginia is typical. In the past three years, the Virginia State contributions to our university have declined by 22% and to our department by 10%; meanwhile our tuition has risen by 30%. No departmental travel or equipment monies are available for the third year in a row. No new positions have been allocated to our department, even though we have arguably the highest workload in the school of engineering. Undergraduate and graduate loads have been increasing with no matching compensation. New demands are placed on us, such as increasing class size and expanding advising. We are pressed to submit more grant proposals even as our success rate has been dropping. University officials remain circumspect about next year's budget because this year's increased tuition triggered a noticeable drop in enrollments, producing a financial shortfall. When some faculty propose changes to give greater emphasis on undergraduate education, others caution that the promotions process will penalize such efforts. When some faculty advocate putting more energy into undergraduate courses, others caution that the state's earned-productivity formulas will penalize such action.

These conditions have generated various moods of anxiety, suspicion, and occasionally resentment among us. Some of us fear that pressure to increase attention to undergraduate curriculum will turn us into a "junior college" and kill our last best hope of becoming great and prestigious. Some of us see calls to "pay attention to undergraduate curriculum" as a proposal to be discussed and resent being told it is a demand of public officials. Some see calls to "broaden the research agenda" as ceding control of research to computational science, biology, physics, chemistry, geology, and others who covet computing research funds. Some see proposals to "support technology transfer" as caving in to the short-term, two-year horizon that is, according to them, killing American business. Some of us urge caution and evaluation of our self-interest before action, while our leaders urge us to focus on the interests of students, parents, high schools, business organizations, and community organizations.

Despite the confusion, we cannot stand still. Which way shall we go?

The Growing Urgency

The situation is compounded by a new mood in Washington and our state capital -- a mood of impatience for action and for change. This shift of political mood is a reflection of a pervasive shift of the public mood that has been occurring over the past five years. Washington is abuzz with talk of a "sea change", referring to politicians' recognition of the new public mood and to discussions about new policies for higher education and research. We are warned that we will have to justify the ultimate social value of our research if federal support for it is to continue.

"Earth shift" is a better metaphor than "sea change". The shift of political winds is not from the tempestuous passage of a front, but from the permanent rearrangement of air currents as the mountains and valleys defining the territory have rearranged.

Numerous signs of the shift can be seen in our state and national capitals. On the resource-providers' side, we see: a) frozen or diminishing dollars for basic research; b) serious talk about shrinking the public support of research and enlarging support of education and technology transfer; c) a national deficit that is growing at 25% annually and forcing widespread questioning of all expenditures; and d) huge payments of national debt (Ross Perot claimed the annual collection of income taxes from all states east of the Mississippi are just sufficient to pay the annual debt interest). Ed David, a former science advisor to the president, recently painted a plausible scenario in which basic research funds are cut 30% in the coming fiscal year. Scientists claim that technology is an engine that powers economic growth while critics say that the engine has gone out of control.

On the consumers' side, we see: a) American students falling farther behind international standards each year.; b) cheaper labor markets in other countries drawing jobs away from the US; c) graduates saying that what we teach does not match what employers are looking for; and d) employers saying our graduates have too much evanescent technical knowledge and insufficient "lifelong" knowledge. Employers want graduates who can function in a fast-paced, internationally competitive, information-based environment. Business executives call for greater connections between university research, undergraduate education, and business interests. They also say that, like businesses, universities can no longer afford to operate without a primary focus on the offers they make and on whether their customers are satisfied with what they deliver.

Other signs of change are apparent. A commission on the future of NSF has recommended a greater interdisciplinary style to basic research, greater emphasis on education, new programs to promote "technology transfer", and a new program of direct funding to businesses. Normally, one would expect such recommendations to take two years to implement; but the Congress must renew the NSF's charter this year. In fall 1992, high-performance computing (HPC) budget of the Defense Advanced Projects Reserch Agency (DARPA) was zeroed, and then restored, a sign that some members of Congress are dissatisfied even with DARPA. The General Accounting Office will soon issue a report critical of DARPA's "favoritism" toward selected US HPC firms. President Clinton proposed to shift $76 billion from military research to civilian research. The Virginia state council on higher education is moving forward aggressively with "Workforce 2000", a plan to reshape curricula to produce graduates who can compete successfully not with Maryland or California, but with Hong Kong, Korea, Japan, South America, or Europe.

Taken individually these signs don't mean much. But the large number of them occurring together is unprecedented.

Science or Education?

What underlies these shifts? Politicians feel safe in criticizing science policy and proposing far-reaching reforms because there is strong public sentiment for such criticisms and changes. Some commentators have proposed that the reason for the public shift is that the "social contract" between scientists and the rest of the society, established in 1945 with the founding of NSF, is coming unraveled (Likins 1992). This "contract" represents the understanding that the government will fund all legitimate research that scientists undertake in pursuit of their curiosity, in return for which science will produce national security, economic prosperity, and public health. Many of the complaints about universities can be interpreted as complaints about non-delivery on some portion of the social contract. Some critics have gone further, claiming that the government has set up a "scientists' welfare system" that has many of the same scandals and defects as the social welfare system.

But the social-contract interpretation does not explain why so many people have become critical of science policy. The amounts of money spent by the government on basic research are well under 1% of the GDP, hardly enough for the average citizen to be concerned about. Why, then, has scientific research become a visceral issue for so many Americans?

The answer lies not in science policy or even the "social contract", but in education. Parents are concerned about the education of their children. In recent years, with books like *ProfScam*, a link has been established in the public mind between the presence of research on campus and the declining quality of the education our young people are receiving. *Many people have come to see the research enterprise as the cause of the decline they see in higher education.* Many see research and teaching as separate, competing enterprises on campus.

The faculty have developed vocabulary that reinforces this perception. The phrase “teaching versus research” is common, but not “teaching and research.” The phrase “buying out of teaching” is equally common. Defenses such as “research is fundamental to the mission of the university” or “the best teachers are the best researchers” reinforce the perception and seem disingenuous to those worried about declining quality of education for their children.

Stinging though these criticisms may be, they are nonetheless real and are affecting our work and our careers. The standard answers about the value of research are falling on deaf ears. The common sense about what is needed to be successful in years ahead differs markedly from what worked in the past.

Toward a New Common Sense

By common sense I mean the conceptual structures that we automatically use to understand the world in which we live. We can already see the beginnings of new conceptual structures in the following convictions that are growing among Congressional and government leaders:

1. The current problems are “structural”. Infusing more money into the current “system” will not cure them; changing in the way the system works will.

2. Universities are the keys to a potential solution. The solution will be achieved by much better education and by universities and business cooperating to produce better curricula whose graduates quickly become productive in their employing organizations.

3. Computing is a central, critical technology. Computing people are being asked to step forward to collaborate with other disciplines and with applications domains, to produce significant improvements in those domains.

From these conclusions emerges a new vision for the role of a department of computing in a university: A partner with other organizations in the transformation of new knowledge into curricula that can be embodied in action by graduates and taken back into the community in which the partners live.

In this context, the answer to the question of justifying the value of research does not lie in the domain of research itself. It lies in addressing the concern about the relation between research and education in universities. How can we reorganize our approach to research so that it is integrated into the curriculum and every undergraduate student benefits?

New Interpretation of Higher Education

Our broad mission is educating people to be competent at living and working in the world that is now and will be in the years ahead. The world has shifted radically in the past decade. The shifts are being accelerated by rapidly declining costs of digital technology and the merging of computers with telecommunications. The current political environment, documented above, is only a reflection of changes that have already happened: politicians are always last on the bandwagon.

Like many other departments, ours follows a traditional approach: we seek to produce graduates who are good programmers and computing-oriented problem solvers. The method of accomplishing this is a large number of presentation-oriented lectures augmented with written homework and programs. We accommodate three degrees of problem-solvers -- BS, MS, PhD -- the two lower degrees each prepare for the next higher, and the PhD is the most prestigious. Except for PhD students, research involvement is low.

But the traditional approach has become dominated with masses of technical detail that will be obsolete in a few years. Here is a list of the lifelong skills that employers, parents, and business executives are now looking for in our graduates:

- Being a “power user” of computing systems and a competent builder of applications
- Balance between practical and theoretical knowledge
- Awareness of need to function in international, networked world
- Ability to work with clients and produce satisfaction
- Skills in communication written and oral
- Ability to communicate a vision and a mission
- Ability to work productively on teams
- Ability to understand and follow instructions
- Eagerness to learn (continuing education)
- Ability to bounce back from adversity
- Flexibility and adaptability in job and career

We cannot create an environment in which students learn these skills by the tradition of presentation-oriented lectures. A number of elements are missing in today’s computing curricula:

1. Students need more “actional knowledge” -- the capacity to act, learned only by active involvement in situations exemplifying those encountered in practice. This knowledge is needed for students to be competent at designing and building applications, which is the primary job function of BS graduates. Current curricula focus almost exclusively on “information knowledge” --

facts, procedures, models, and processes learned through passive listening in lectures.

2. Students need more “systems thinking” -- the capacity to interpret an organization or group as an interacting set of humans and machines and act on that interpretation. This knowledge is needed for MS graduates to fulfill their primary job function: to be competent at diagnosing organizational problems, at designing computing systems that will assist people in carrying out the recommended changes, and to manage the teams that build those systems. Current curricula offer mostly coursework at the masters level, but do not cultivate systems thinking.

3. Students need to learn about the processes of invention and innovation in order to be contributing members of “learning organizations”. Invention means the construction of new machines or devices to assist work, and innovation the incorporation of inventions into daily human practices. Current curricula treat research as a separate enterprise reserved only for selected graduate students and have no contact with processes of invention in business.

4. Students need to learn how to learn. They will constantly face new challenges for which their current knowledge is insufficient. Many will be called upon to change careers. They need basic skills at tracking down useful information and data, at practicing new skills, at locating experts, and at building networks of people through which to observe the world. They need access to continuing education services. They need to be teachers themselves in their own groups and organizations.

The three accompanying figures suggest the direction of the transformation that would provide these missing elements. Figure 1 depicts the current situation, the model of university education according to our current common sense: a pipeline from high schools through the three levels of BS, MS, and PhD, where PhD is seen as the noblest height to which a student can aspire, a peak that only the few brightest actually reach. This model has nothing to say about what happens to the students leaving the pipeline with their BS or MS degrees; we assume they take their education and get jobs. This model is based on the notion that the social function of the university is to pass knowledge on to students “flowing” (in proper gender and ethnic mixes) through the pipeline.

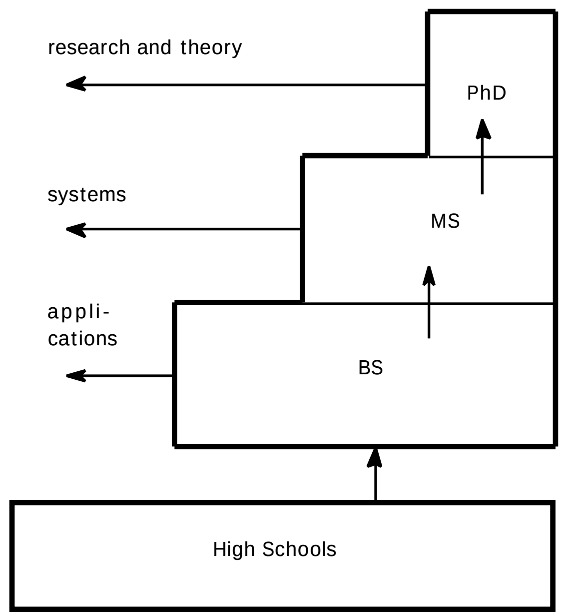

Figure 1: Pipeline Model

Figure 2 depicts an expanded view that makes explicit the connection between universities and business and government organizations. Most of these organizations see the BS degree program as serving the function of preparing its graduates to be applications designers and implementors. They see the MS degree program as providing its graduates with systems thinking, the ability to see organizations as systems composed of machines and people and the capacity to design and deploy useful computing systems in those organizations. They see the PhD program as preparing its graduates for research and theory. Many of today's complaints about practical competence of BS and MS graduates reveal a mismatch between the expectations of business and government organizations and the faculty who design and implement the curriculum. It is important to see and understand the link between universities and other organizations, because the latter are defining the world in which the graduates of the former must live, work, and be competent. A large number of the complaints would vanish if the BS and MS curricula were redesigned to produce students good at applications and at systems, respectively. The redesign will have to be a cooperative effort between university faculty and representatives of business and government organizations. The nature of a redesign at the BS and MS levels has been discussed in my paper about education (Denning 1992). It highlights the method of exhibitions as a way of developing applications skills and other "actional" skills at the BS level. The report from the National Research Council, *Computing The Future* (1992), which was authored by a panel of distinguished researchers from university and industry, calls for greater attention to be paid to undergraduate curriculum. It also suggests the nature of a redesign at the PhD level: a greater emphasis on interdisciplinary research between computing and other fields, supporting the generation of new knowledge in those fields.

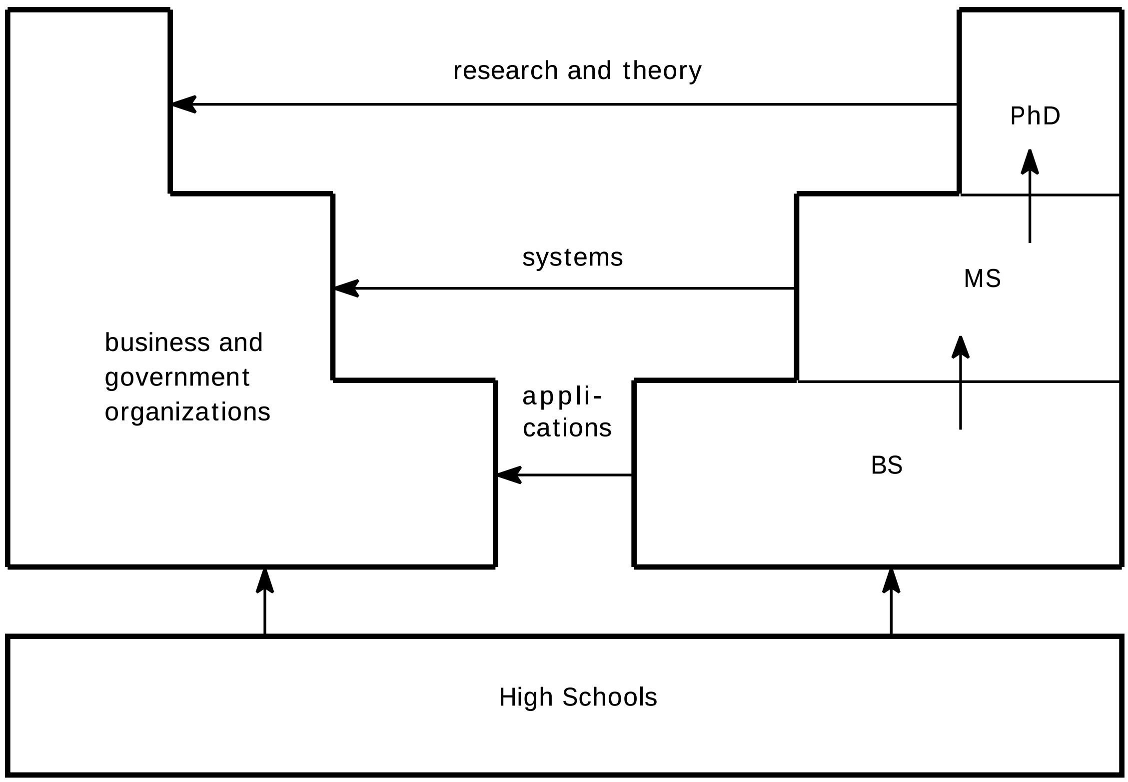

Figure 2: Pipeline Model with Customers

The redesign suggested by Figure 2 is not enough to address the complaint that research produces no tangible benefit for BS and MS students. Figure 3 expands the view to add a feedback loop from the research domain to the MS and BS curricula (and on into the high schools). The feedback loop would allow students to come into contact with the leading edges of science and technology. An approach -- by no means the only one -- to implementing the feedback loop would be as follows:

1. Construct a core HPC (high performance computing) laboratory for undergraduates that has links to other campus computing facilities, to the facilities of participating regional business and government organizations, to the national HPC network, and to high schools.

2. Facilitate the flow from research to the curriculum by assisting research faculty in porting software illustrating research results through demonstrations, simulations, and interactive presentations into the laboratory.

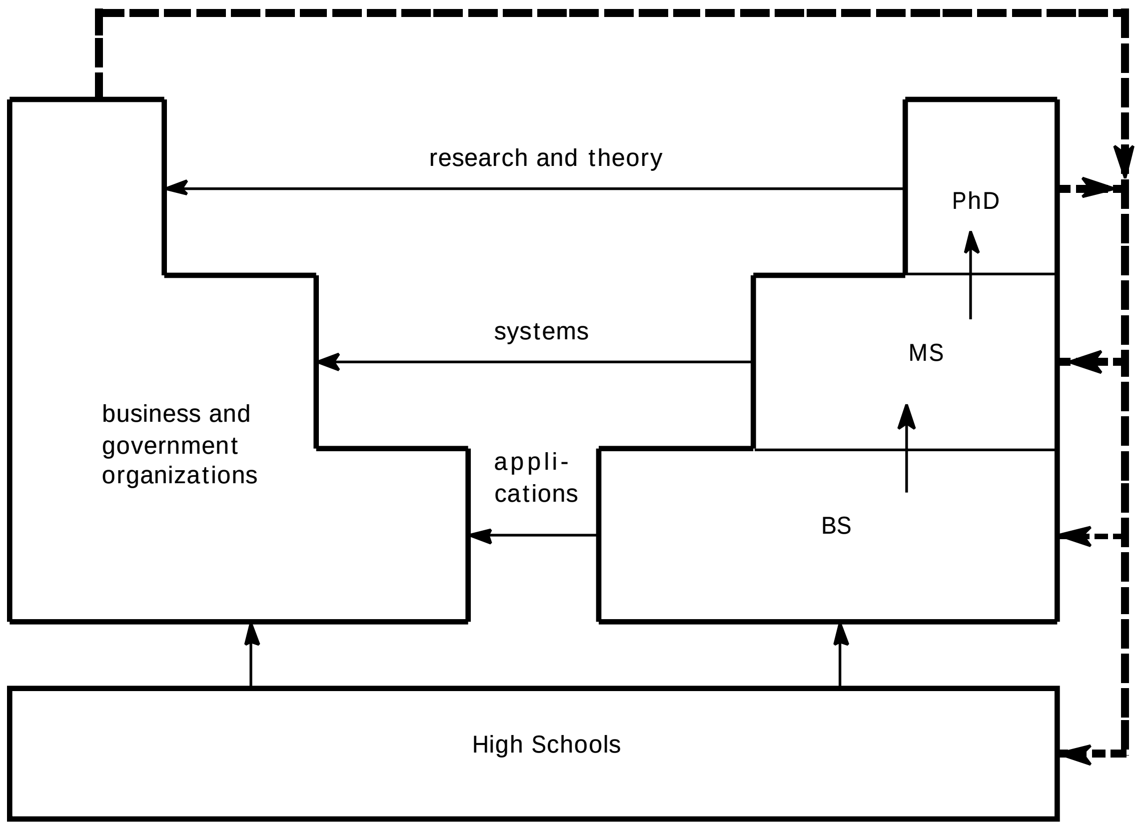

Figure 3: Pipeline Model with Customers and Feedback

3. Set up the laboratory system so that large numbers of students can use their PCs to gain access to the core facilities through the network and through scalable versions of software. A piece of the lab will thus live in each student's PC.

4. Establish working links with business and government organizations who will supply design projects for students using the laboratory; successful projects will contribute to the organization that proposed them.

5. Establish links with high schools to give them the opportunity to elevate the skills of their graduates who aspire to college. Organize seminars for teachers.

A New Social Contract

Computing technologies will not cure our ills. In fact, the belief that putting more computers in the classrooms and labs will *ipso facto* improve education is part of the old common sense. The new common sense lies in valuing alliances and partnerships with other organizations and groups. The technology helps facilitate and support those social relations.

The terminology of the "feedback loop" in Figure 3 can be misleading if taken too literally. What we are actually talking about is universities and high schools designing a new social function for themselves: a partnership with other organizations that transforms their new knowledge into curricula, knowledge that can be embodied by graduates who take it into their communities and employing organizations and put it to action.

Benefits

We have proposed a new interpretation of the social function of a university in which research would be an integral part and would contribute tangibly to the undergraduate curriculum. If we were to cultivate this interpretation and start acting in it, we would sustain research in our universities; and a rich set of benefits would come to our students and us:

1. Maintain a level of study and inquiry beyond what is possible at junior colleges.
2. Build a curriculum that students flock to, an attraction of best students particularly from local high schools.
3. Maintain a research program that is appreciated by the public because it is accessible to their sons and daughters, who learn from it.
4. Gain access to new research funds restricted to interdisciplinary or technology transfer activities.
5. Be strongly positioned for credible access to new monies for support of education innovations: be the first out of the gate while others are still wondering if there is a race.
6. Attract new state resources to our department because we are engaging in educational innovation.
7. Raise new revenues from education partnership with business organizations.
8. Gain the satisfaction at seeing our students succeed in the world.

9. Gain the satisfaction that our research is valued (used) by business, students, and public as well as peers.
10. Eliminate attacks on our professionalism.
11. Control our own destiny rather than being told what it is.

We can dream of a time in the not-distant future when our students look forward to learning because they see the connection between school and the world, because we are teaching them lifelong skills, and because they are active participants in the generation of new educational aids.

We can dream of a time in the not-distant future when our students can go home and say to their parents, “Mom! Dad! Did you see the supercomputer that was simulating a biologist connecting DNA strands to search for genes that resist Alzheimer’s disease? I did that today in lab! I know how it works!” Thus would end the illusion that research and education are separate enterprises in our universities, competing for the same limited resources and faculty time.

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