ASEE Conference Proceedings, June 1995

Session 1697

Re-engineering the Engineering School

Peter J. Denning, Daniel Menascé, Joseph Gerstner
George Mason University

Introduction

Who is the educated engineer of the 21st century? Who must we as faculty become to cultivate that engineer? These are the two guiding questions of the Center for the New Engineer (CNE), established in August 1993 at George Mason University. We have undertaken this exploration from our urgent concern for the continued health of engineering in face of sharp and still-escalating public criticisms of universities [12, 13].

We began by considering the engineering school as part of a larger social system including K-12 schools who send us their graduates, business and government organizations that hire our graduates, and regional communities who expect to contribute to and draw on the expertise of our faculty. The engineering curriculum is preparing the first group for employment by the second in the context of the third. The curriculum cannot produce satisfaction for all parties unless it is designed in and from this system perspective.

Our initial projects have been designed to address four critical elements that are presently missing from this system:

- Coupling from research to non-PhD education
- Curriculum attuned to future markets
- Regional community
- Effective engineering-school work coordination processes

To address the first problem we are creating a library of Internet-based tutorial modules that allow undergraduate students to explore, navigate, and experiment with advanced technologies in computer science, computational science, and engineering. To address the second problem we have developed the Senior Design Exhibition program, featuring teams of students designing systems that must satisfy outside customers; this program is being imitated throughout the entire engineering school. To address the third problem we have created an affordable regional network among K-12 schools, CNELink, and we have established a training system for teachers and students. To address the fourth problem we are using the Action Workflow system to map and facilitate internal business processes, and Lotus Notes to facilitate workgroup communication.

The Problems: A Systems Perspective

We are witnessing a massive loss of public confidence in universities. In 1994, more states followed the lead of the 26 that cut funds in 1993 for higher education; two more authors joined the parade critical of universities (5, 10, 12, 13, 14). Four themes recur in all the criticisms: 1) research is an expensive, separate enterprise that competes with and draws energy away from undergraduate teaching; 2) faculty have come to regard federal research funds as an entitlement and have tolerated numerous problems with overhead fraud and pork-barrel projects; 3) faculty are not sensitive to commercial needs, notably for a balance of theoretical and practical skills among graduates; 4) faculty misuse the job security of tenure to maintain low student contact time and high outside consulting work. While they may be gross generalizations from a few bad cases and a few misunderstandings, these perceptions must be taken seriously. They must be refuted, not just with arguments, but with actions.

These problems all share a common feature: they are communication problems. They reflect misunderstandings of what engineering schools do, and they reflect a lack of awareness by the faculty for important concerns outside the university. The starting point for resolving these problems is a map of the entire social system including the engineering school, other schools, and employing organizations. Our traditional map is the pipeline model showing the "flow of students" into college from high schools and out from college with BS, MS, or PhD degrees.

But the pipeline map obscures most of the story. The students who "flow out" almost always take a job with a business or government organization. Their employers almost always have strong expectations about what they should be able to do. We need to enlarge the map to show explicitly the organizations that employ our graduates, and we must add arrows from them to the university representing their "flow of expectations". Because the PhD program is not the only source of new knowledge in the community -- many companies have R&D groups who would like to see some of what they are learning feed into the education system -- we must add an arrow from them to the university representing the "flow of new knowledge", and we must continue that arrow

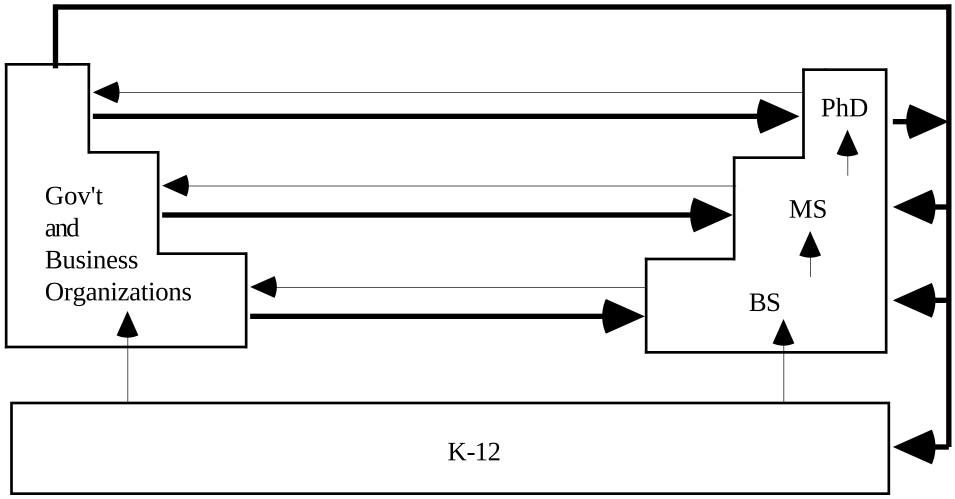

Figure 1. The engineering school is often thought of as a pipeline channeling graduates from K-12 schools to government and business organizations (light arrows). It must be more. The engineering school must activate new communication paths: from research in government, business, and university to curriculum; from university to K-12; and from business market concerns to university (heavy arrows).

from the PhD program into the BS and MS curricula. Finally, most engineering faculty profess dissatisfaction with the preparedness and discipline of high school graduates coming to college, and yet few take the time to confer with teachers from those schools about curriculum. We must add an arrow representing the "flow of curriculum" between the university and the K-12 schools.

Figure 1 shows a new map resulting from these additions. This map suggests that we need new tools and new practices to activate the missing feedback paths. Computing and telecommunications technologies offer special opportunities for new tools. Our projects in the Center for the New Engineer are oriented toward providing tools and cultivating the new practices that will in turn remove the bottlenecks to the missing feedback paths and establish us as a full member of the regional community of schools and employers.

Connecting Laboratory to Curriculum

Perhaps our biggest problem is that research and education have come to be seen by many students and employers as opposing enterprises; critics believe faculty would choose research over teaching if given the chance. They base their perception partly on a belief that faculty get most of their professional recognition from publishing papers and winning grant awards, and partly on an observation that research labs are better equipped than the normal student labs. It is easy to conclude that this is an infrastructure problem. With a good infrastructure, many believe, faculty could communicate with students more readily, assign more lab work, and assign more challenging projects.

This is true as far as it goes. Now that computer processing power and memory are affordable and the Internet is ubiquitous, the differences between equipment in research and student labs is narrowing and email communications with faculty are improving. The arrival of the World-Wide Web has, however, brought new problems, notably hordes of students who overwhelm network and server capacity and get lost in vast seas of information. Simply providing the infrastructure is not good enough. We need new practices for effective load control, navigation, and exploration.

Our approach in CNE has been to explore the infrastructure and navigation problems in parallel. We have implemented a lab facility that allows us to experiment with methods of providing affordable access to high-performance computing equipment, and we have undertaken a program of implementing CNE tutorial modules.

Infrastructure. Our CNE computing laboratory consists of a Sun server with a direct T1 connection to Internet and a variety of multimedia-capable workstations (Suns, Macs, and 486s). We have provided every CS faculty member with a Sun LX workstations and connected them all on the CNE-subnet to the lab. We have worked closely with the campus computer store to define a base configuration of a PC for students. We are conducting experiments whose goal is to find an affordable configuration that will allow students full, remote use of the lab from clients with X-windows or Web readers, complemented with new project practices in which students test and edit in standalone mode before connecting to the server for full-blown demonstrations of their projects. We are also planning a test of a cheap, local network such as infrared that could turn any classroom into a lab: portable PCs linking to the instructor's computer for the duration of the class period.

CNE Modules. We have spent calendar 1994 designing and implementing an initial library of multimedia modules that serve as explorers and navigators of subjects of contemporary research. These modules are the conveyances by which faculty can transfer their research knowledge to students. Each module offers tutorials, demonstrations, and workbenches. The modules are Internet-compatible because many of the objects they reference are found elsewhere and because many researchers are adopting the practice of establishing home pages for their research projects and personal collections of scientific papers. The home page of a module declares the authors, the copyrights, permissions from other copyright holders, and a means to send comments to the authors. The home page also takes the viewer to a map that depicts the research area. We have styled our maps after a city subway system; the lines suggest initial routes of navigation and the stations are linked to sections of the module. Clicking on a station takes the viewer directly to that section of the module. Figure 2 is an example of a map for one of the modules. Eight modules are now available via the CNE home page (http://cne.gmu.edu:80):

network protocols
ATM systems
genetic algorithms
virtual memory
distributed shared memory
scalable distributed systems
system performance evaluation by queueing models
workflow management technology

These modules are also prototypes of a new kind of publication, the *dynamic book*, that will become common.

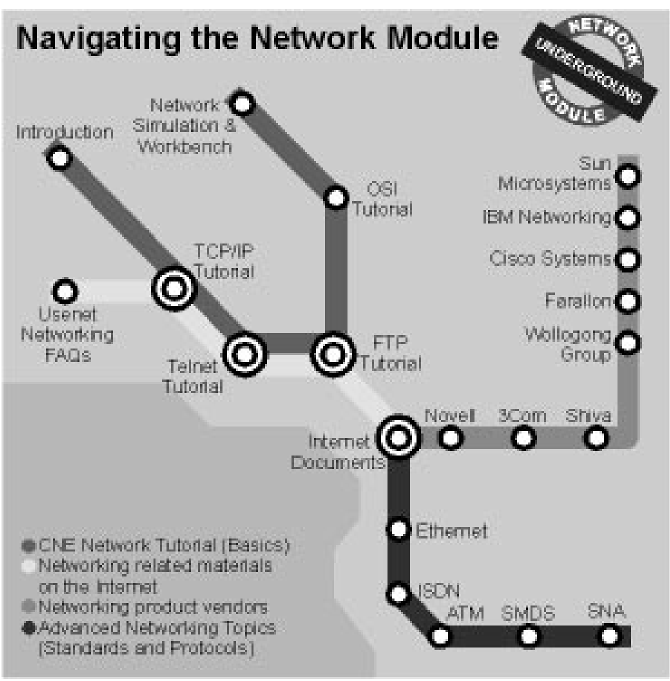

Figure 2. A "subway map" introducing the network module.

Our long range goal with these modules is to provide packages that can be used in courses to assist in teaching portions of the material. Using the package, students will explore the topic, read the tutorials, exercise the demonstrations, and perform experiments on the workbench. At some point this can become a new mode of publication embraced by commercial publishers.

The last three of the above modules were supported by a grant from NSF to promote coupling of research and curriculum. We are specifically looking to import tools for dealing with complex systems, already in use by researchers in other disciplines, into the engineer's design portfolio. In 1995 we will add three more modules of this kind: particle simulation methods, fluid dynamics, and image analysis.

But these packages will not be built unless faculty find it easy to construct and maintain modules about their research areas. This calls for an authoring system. After one year of working on these modules, we now understand their architecture and the annoying technical problems that must be hidden from authors. We are beginning work on an author's package that will assist faculty to create and revise their subway maps and link them to other module components. Some of the technical problems that must be overcome in the next generation of modules include secure spawning of processes for demonstrations and workbench, easy graphical interfaces for demonstrations and workbenches, running software on other computers, and security. These are all things for which technologies exist; the problem is to bring them together into a working unity.

Attuning Curriculum to Future Markets

Employer complaints about the qualifications of graduates are all too familiar. High on interviewers' most-wanted lists are social skills including teams, communication in writing and in speech, flexibility, managing adversity, and persistence. Engineering technical skills have not disappeared from the list, and are absolutely essential; but the traditional engineering curriculum does not cultivate these social skills and has become a big breakdown for employers. The prospect of major curriculum reform in order to achieve a new balance between rigor and practice is so daunting that few faculties have the stomach for it. It is not easy. We are exploring a more gentle approach.

The real bottleneck here is poor communication between employers and faculty. The evolving concerns of businesses have gradually drifted apart from the concerns of faculties, until finally the gap is large enough to cause complaints. As a means to improve working relationships between faculty and business, to allow each to become more familiar with the concerns of the other, and to give greater assurance that students can combine rigor and practice, we have instituted a program called Senior Design Exhibition [6, 7].

The essence of this program is that teams of three students, under the supervision of a faculty member, spend a semester designing a software system to solve a problem posed by an outside customer. The student team must create and work to a schedule satisfactory to the customer, and must complete the work on time by the end of the semester. All teams make presentations at a symposium at the end of the semester, where they exhibit and defend their projects. A satisfactory grade will not be awarded unless the customer is satisfied. The role of the outside customer is the main aspect that distinguishes this program from the traditional engineering senior capstone design project. We have offered this course twice on an experimental basis, with strong positive results and enthusiastic response from local companies and from students. Several of the students subsequently accepted job offers from their former customers. The Design Exhibition has become a model that is being imitated by the other undergraduate programs in the school of engineering.

Our short experience with this program has been also been illuminating. All six projects to date have emphasized the design of a system that integrates many existing components, such as windows, operating systems, database management systems, servers, and graphical user interfaces. The students had to ascend a steep learning curve to achieve an understanding of these components, and then they had to successfully bind those components together into a coherent system. We have concluded that systems design and integration are and will remain big concerns for employers and that our curriculum does not prepare students adequately for this type of concern. We are looking for ways to revise our curriculum for greater emphasis on rigorous analysis of problems and the practice of designing systems by integrating many existing components.

Administering an exhibition program can be quite labor intensive because there are many potential customers, many inquiries, and many interested students. Without a means of taking care of the relationships between faculty and businesses, the program will collapse. We think that, with proper tools, we can keep the total work to the level that a faculty coordinator can manage the program in the normal amount of time that would be expected of a committee assignment. We are designing such a tool now and will make it accessible from the CNE home page.

The tool is a Senior Design Exhibition Module built in the style of the CNE tutorial modules. This module contains a map of the process students must undertake to complete a design exhibition satisfactorily. It advertises projects, faculty advisors, and outside customers. It provides a means for a company to post a project in a standard format and obtain a faculty advisor. It provides a means for students to apply for membership in projects, including projects in different departments from their majors. The module is accessible from our home page.

CNELink: Regional Community of Schools

Engineering faculties are finding that a growing number of incoming students are incapable of performing basic actions in mathematics and programming, certifications on their high-school transcripts notwithstanding. These faculties are finding themselves increasingly eager to influence the curricula of high schools and, to a lesser extent, K-9 schools. They would also like to influence more students toward interest in science and engineering. For their part, teachers in the schools would welcome assistance from faculty and graduate students in improving their science and math curricula.

Given all the good will on both sides, a straightforward technology to facilitate communication would be a winner. For this reason, the CNE has undertaken to build a prototype of an affordable regional network that connects the university and K-12 schools into a common network within the Internet. We call our prototype CNELink. CNELink currently encompasses 12 schools in Alexandria, Arlington, Fairfax, Prince William, and Montgomery Counties.

The word "affordable" is extremely important here. We could bring the Internet into any school in the matter of a few weeks by purchasing a Unix box and a T1 line -- at a cost of $10,000 for the box and hardware and $2,000 per month for the line. Not only do most schools lack the funds for this, they do not want to have to deal with Unix system administration. What they typically want is for someone to make their current 386 or 486 server Internet-compatible and to supply as much bandwidth as possible for $100 or so per month. They also want training and a hot line to give them technical assistance after the initial installation and glamour wear off.

We have accomplished this. In doing so, we had to jump two major hurdles. One was a large amount of legwork to resolve politics, scheduling, budgets, understandings of their current computers and LANs, training, and myriad other details with each of the schools. The other was an architecture that did not cost much and could be easily configured for the kinds of server platforms (286, 386, 486, Pentium, and DOS/Windows) and the kinds of network software (Novell 3.x and 4.x and Apple LocalTalk) already in these schools. The hardware connection between the communication line and their local networks was accomplished with a DigiBoard. We provided 128K bandwidth ISDN lines from each school to the university, with monthly costs averaging under $100. The Community Learning and Information Network took the lead to solve these problems and help us bring CNELink on line in November 1994. It did not take long for teachers to begin putting CNELink to good use. Within a month, we had a note from one of the teachers announcing that her students had already done a project on South Africa using materials they had discovered in the Internet. She saw the Internet as a powerful, new research tool for her students.

After we are sure all the schools are stable, we will be turning to other experiments with them. One experiment will involve video-on-demand for access to curriculum materials. Another will involve cooperative-work software (e.g., Lotus Notes) that will support student project teams and connect them with outside mentors. A third experiment will involve showing teachers how to use the CNE module authoring tools to create their own curriculum materials.

We are extending the CNELink in a number of ways. One is to work with a “champion” who steps forward to coordinate the school’s requirements and resources with our program and thereby add the school at minimum cost. Another is to work with an existing or emerging school system local network, providing them Internet access through our router. This is being done with the Arlington and Fairfax County districts, where we have provided early connections, technical support, engineering help, and training. As they gain in experience we will help them transition to independent operations. A third approach has been key alliances, such as with an NTIA project hosted by our university, for whom we will provide access to the Internet via our router.

Workflow: Re-engineering Academic Coordination Processes

The fourth major problem area is inefficiency of academic work processes. These processes include advising, course scheduling, personnel actions, coordinating classes, grading papers, procurements, reports to the government, program assessments, and the like. As universities get leaner with their shrinking budgets, they will have to learn how to use computing technology to automate many of these time-consuming processes and manage them with fewer personnel. As we succeed with this, the faculty will have more time to devote to helping their students learn, and to experiment with new course formats involving Internet delivery.

The bottleneck here is the inability to observe and map work processes and determine where the breakdowns and bottlenecks are. In our lab, we have set up experiments with the Action Workflow system to demonstrate possible resolutions of the breakdowns [4]. This technology allows us to draw maps of the coordination processes underlying all these other processes, to create database representations of the maps, and to track progress in them as people take actions. At the same time, we can remove unneded steps, eliminate most paper forms, store representations of them in the computers, and affix all required signatures digitally.

Our first experiment with this technology started with hand-drawn maps of the process of student advising. We developed a set of databases in Lotus Notes. We placed a Notes server on the CNE server and Notes clients in each faculty workstation. When a student arrives for an advising session, the faculty member can quickly display a copy of the student’s transcript to the screen, and also a facsimile of the department’s graduation checklist form that shows what requirements a student has thus far satisfied.

We will soon install Notes on the engineering-school server to support selected experiments with its use to conduct classes. One scenario we envisage is a teacher-to-student database in which the teacher can place all homework sets, announcements, and course notes; students can comment and the instructor can answer their questions, all in the database. A second database would allow students to send in homework electronically. A set of conversation databases could be established, one for each student study group or project team.

Another experiment will involve a system called Ceilidh from the University of Nottingham. Ceilidh grades student programs in C++. We will use it in our introductory programming courses to see if we can free up significant amounts of instructor and teaching-assistant time for more student coaching and for the important work of maintaining the curriculum [11].

This is a small start. Much bigger opportunities await: course scheduling, personnel actions, procurements, and senior design project coordination.

Conclusions

Our driving concern is the health of engineering education. There are major complaints and, if we do not respond effectively to them, we may well find bureaucrats micromanaging the system. Among universities as among governments, central planning and control can never be as effective as free competition [9].

A systems diagram reveals feedbacks that are missing in our education system. We do not have to reform the entire system in order to put back the feedbacks. Any school or department can undertake to do this at their level. The Center for the New Engineer has been studying technologies that would allow the missing paths to function without asking the faculty to take on a new burden of coordination work.

Even the critics admit that the US education and university research system is the envy of the world. Students from all over the world come to this country to be in our engineering schools. But we cannot rest on the strong reputation our system has already achieved. The mission of the university cannot be served by faculty who do not endeavor to be technology leaders in some way. Research is a form of “sharpening the saw”, the necessary work to keep up to date on advancing technologies for the benefit of students and others who wish to draw on the faculty’s expertise.

Acknowledgments

Numerous people have assisted in the CNE. These include the CLIN team of Sam Wyman (director), William Pierce, Vince Darago, and Christine Tillotson. Bridget Robey did much of the legwork for the initial CNELink. Alan Schultz, Mitch Potter, and Tom DyBala have provided much technical expertise in the establishment of the HPC lab and Internet connections. Sanjeev Setia worked out an architecture of experiments for affordable X-window access to the lab. Gary Quisumbing got the Notes server working and has been its administrator. Michael Hieb set up the Action Workflow System and authored the module on workflow technologies. Amar Rao authored the module on scalable systems. Gary Quisumbing, Hai Le, Alfred Jones, Srinivas Surapaneni, and

Anantha Bangalore authored the network protocols module. Priscilla McAndrews, Jill Bobbin, and Srinivas Tata authored the virtual memory module. Naval Deshbandhu, K. Park, and Anantha Bangalore authored the genetics algorithms module. Srinivasa Valluri and Sudanshu Killedar authored the system performance evaluation module. Zhen Zhou authored the CNELink module. Ellen Ellis led the team that proposed the initial architecture of the modules. Debora Cole has been the primary liaison with Lotus Development Corporation and Raúl Medina-Mora with Action Technologies. ARPA has supported the CNE through its contract DABT63-93-C-0026. NSF has supported the modules that represent approaches to complex systems from other scientific disciplines through its grant EEC-9315576.

Locating CNE In the Web

The CNE modules, CNELink, and other aspects of CNE can be accessed via the CNE home page in the World Wide Web: URL http://cne.gmu.edu:80.

References

1. ACM. 1994. Special Issue on Hypermedia. *Communications of ACM 37*, 2 (February).

2. ACM. 1994. Special Issue on K-12 Education. *Communications of ACM 37*, 5 (May).

3. ACM. 1994. Special Issue on Internet Technology. *Communications of ACM 37*, 8 (August).

4. Action Technologies. 1994. *Manuals for the Action Workflow Analyst, Builder, and Manager.* 1301 Marina Village Parkway, Alameda, CA 94501.

5. Anderson, Martin. 1992. *Impostors in the Temple*. Simon and Schuster.

6. Denning, Peter J. 1992. "Educating a new engineer." *Communications of ACM 35*, 12 (December).

7. Denning, Peter J. 1993. "Designing new principles to sustain research in our universities." *Communications of ACM 36*, 7 (July).

8. Denning, Peter J., and Raúl Medina-Mora. 1995. "Completing the loops". ORSA/TIMS *Interfaces* (May).

9. Hayek, Fredrick A. 1988. *The Fatal Conceit*. University of Chicago Press.

10. Huber, R. 1992. *How Professors Play the Cat Guarding the Cream*. George Mason University Press.

11. Knight, John, Jane Prey, and William Wulf. 1994. "Undergraduate Computer Science Education: A New Curriculum Philosophy and Overview". Proc. ACM SIGCSE Symposium (March).

12. Roche, George. 1994. *The Fall of the Ivory Tower*. Hillsdale College Press.

13. Sykes, Charles. 1988. *Profscam*. St Martins Press.

14. Wilson, Kenneth, and Bennett Daviss. 1994. *Redesigning Education.* Henry Holt.